USING SALINE WATER FOR CROP PRODUCTION
IN NEW MEXICO

by

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ABSTRACT

New Mexico has vast supplies of saline groundwaters whose use could expand irrigated agriculture and conserve good quality water for domestic use. Unfortunately, little is known of the long-term effects of such waters on soils and crops common to New Mexico. Thus, two studies were conducted to determine the feasibility of using various salinity waters (total dissolved solids 1,250-15,000 mg/l).

Greenhouse data suggest that the most realistic way to utilize saline waters is as supplements to normal fresh water irrigations. The degree of supplementation possible without severe yield reductions varies inversely with water salinity. However, very saline waters (10,000 and 15,000 mg/l TDS) are not likely to be of practical use for common agricultural crops at any degree of supplementation.

Using saline water as the sole source of irrigation water is reasonable for long-term cultivation of common crops only with the lowest salinity water (1250 mg/l TDS). One season emergencies may be met with waters as saline as 2,500-5,000 mg/l TDS, but continued use will severely reduce yields.

Keywords: Salinity, water management, groundwaters, supplemental irrigation, salt tolerance, greenhouse studies, sorghum.

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INTRODUCTION

The abundant underground water supplies of New Mexico and of many areas of the world, remain largely unexploited due to the high concentration of salt in these waters. Of the approximately 25 x 10^{12} cu meters (20 billion acre-feet) of underground water storage in New Mexico (U. S. Department of Interior, 1976), about one-quarter is classified as fresh (total dissolved solids - TDS = less than 1000 mg/l) or only slightly saline (TDS = 1000 - 3000 mg/l). The remaining 19 x 10^{12} cu meters (15 billion acre-feet) is characterized as either moderately saline (TDS = 3000 - 10,000 mg/l), as very saline (TDS = 10,000 - 35,000 mg/l), or as brines (TDS = 35,000 mg/l). The recoverability of this huge reservoir is largely unknown and much of the water is so saline that there has been little effort to utilize these aquifers. Recent success (Epstein and Norlyn, 1977) in growing crops with sea water however, has kindled new interest in saline water usage. The ability to successfully use saline water to grow common agriculture crops could 1) expand the acreage of irrigated agriculture and hence increase food, fiber, and renewable resource fuel production, and 2) conserve some of the good quality water for alternate uses such as domestic and industrial consumption.

Unfortunately, little is known about the long-term effects of irrigating with very saline water since most soils research has centered on minimizing the salt levels in soils. The data that are available involving saline water are for very salt tolerant species such as desert shrubs or grasses (Stewart, 1967) or for agricultural crops on very sandy soils such as sand dunes (Epstein and Norlyn, 1977). Other studies involving saline waters have used waters only slightly saline (Moore and Murphy, 1978), or were conducted in areas in which natural rainfall was sufficient to leach soil profiles prior to the growing season (Miller, 1979). Such studies often yield optimistic results that may not be appropriate for other agricultural regions. Dregne (1969) has predicted the long-term effects of increased salinity on the yields of agricultural crops in New Mexico, but very limited data are available to test his predictions. The lack of data is particularly severe at the very high salinities that characterize New Mexico's underground water supplies.

The purpose of this research was to determine the effects of using waters characteristic of saline groundwater in New Mexico on crops and soils common to the state. The approach was to grow plants in the greenhouse using saline waters in irrigation schemes expected to be practical in the southwest.

MATERIALS AND METHODS

The effects of various saline waters on sorghum yield were determined in two greenhouse experiments. Experiment one determined the effect of the exclusive use of various saline waters on sorghum yield in three soils. Experiment two studied the effect of saline waters used to supplement fresh water on sorghum yield over the equivalent of three growing seasons.

Experiment One

Five saline waters (Table 1) were used to irrigate each of three soils. Total dissolved solids (TDS) contents of saline waters ranged

Table 1. Characteristics of synthetic waters used in the study.

Characteristic	Water					
	Saline					Fresh
	1	2	3	4	5	
TDS (mg/l)	1,250	2,500	5,000	10,000	15,000	150
SAR	16	22	32	44	57	3.2

from 1,250 to 15,000 mg/l, while sodium adsorption ratios (SAR) varied from 16 to 57. Groundwaters in New Mexico differ in chemical composition, but Na^+ is usually the dominant cation. Thus, the five saline concentrations used consisted of 85% NaCl and 15% $CaSO_4$, typical of the vast groundwater supplies of New Mexico (U. S. Dept. of the Interior, 1976).

Soils of three textures, sand (Sheppard series), sandy loam (Doak series), and fine sandy loam (Lea series) common to New Mexico, were selected for experiment one. Representative chemical and physical properties of each soil are given in Table 2. Twenty centimeter pots were loosely filled with the soils. Each soil-saline water combination included water applied at two leaching fractions (0.15 and 0.30) and was replicated four times for a total of 120 pots.

Several sorghum seeds (_Sorghum_ _bicolor_ var. savanna) were planted in each pot and watered with tap water until they germinated. Saline water irrigations were then applied weekly. Irrigation volumes were determined by weighing each pot and determining the amount of water lost from the previous "field capacity" weight. This water loss was then divided by either 0.85 or 0.70 (1-LF) to calculate the volume of water needed to replenish the pot and to provide the necessary leaching fractions. Irrigations were conducted at night to reduce evaporational losses. Each pot was weighed the next morning to determine the new "field capacity" weight. Drainage was collected in receiving flasks below each pot. One replicate of each treatment had salinity sensors installed half way down the soil column to follow soil salinity changes.

Table 2. Selected physical and chemical properties of soils used in salinity studies.

Soil	Texture	Particle Size (%)			Electrical Conductivity (mmho/cm)	Paste pH	$\%CaCo_3$	CEC(me/100g)
		Sand	Silt	Clay				
Blue point	sand	92	3	5	0.45	8.4	2.8	5.7
Doak	sandy loam	67	19	14	0.56	7.6	0.9	10.9
Harvey	sandy loam	67	19	14	1.45	7.7	0.5	14.0
Lea	fine sandy loam	66	19	15	0.81	7.8	11.0	14.1
Sheppard	sand	94	3	3	0.32	8.2	0.1	1.4

Each pot was fertilized with the equivalent of 187.5 kg N and 212.5 kg P/ha with $NH_4H_2PO_4$, and with 9.33 kg/ha of Fe as the chelate FeEDDHA about 1 week after germination. Three or four days later, each pot was thinned to yield 3 plants per pot. After 8 weeks plants were harvested at ground level, rinsed, and dried. Yields were expressed as grams of dried plant material per pot.

A second sorghum crop was grown in the same pots, in the same manner as the first except that all irrigations, including germination irrigations, were with saline waters.

Experiment Two

The same five saline waters described previously were used to irrigate two additional soils, a sand (Bluepoint series) and a sandy loam (Harvey series). These textures were selected as being representative of soils found throughout New Mexico (Table 2). The saline water was applied at four different frequencies. Frequency one consisted of fresh water applied for the entire eight weeks of the experiment; frequency two used fresh water for the first six weeks of irrigation, and saline water for the remaining two weeks; frequency three consisted of four weeks of fresh water irrigation, followed by four weeks of saline water irrigation; and frequency four used a two week fresh water, six week of saline water schedule. Each soil-saline-frequency combination was replicated three times for a total of 120 pots.

Bulk samples of the soils were crushed, passed through 6.4 mm screen and loosely packed in 20 cm pots. Each pot of soil was irrigated with tap water to equalize initial salinities and to determine the pot water-holding capacity ("field capacity") after free drainage. Before the last of these three pre-irrigations, the pots were fertilized as in experiment one. In January, twenty sorghum seeds were planted in each pot and were later thinned to three plants per pot, attempting to retain plants of uniform size throughout the plot.

Irrigation volumes were determined by weighing each pot and subtracting their current weight from that at pot capacity. That volume of water needed to return the pot to "field capacity" was then added to each pot. No additional water for leaching was applied during the growing period. As before, irrigations were applied in the evening to reduce water loss by evapotranspiration. The pots were reweighed in the morning to determine the new pot capacity. Salinity sensors installed half way down the soil column in one replicate of the experiment were used to follow soil salinity changes after each irrigation. The pots were irrigated once a week for the first three weeks and twice a week for the remaining five weeks. At the end of eight weeks the plants were harvested at ground level. After harvest, enough fresh water to produce a leaching fraction equal to .20 of the total volume of irrigation water was applied to the pots. The small amount of drainage occurring after irrigation throughout the eight weeks was considered in the overall .20 leaching fraction.

In March, the pots were refertilized and a second sorghum crop planted. In May, a third crop was planted and grown in the same pots under the same conditions and treatments. In each case, harvested sorghum was dried as in the first experiment to obtain yields expressed as grams of dry plant material per pot.

RESULTS AND DISCUSSION

Experiment One

Sorghum yields as a function of water salinity and leaching fraction for both cropping periods are given in Table 3. Leaching fraction had no significant effect on yield in the first crop, and had inconsistent effects on yield in the second crop. However, sorghum yields in the second crop tended to be less in those pots receiving the smaller leaching fraction. The decreased growth was probably a reflection of the higher salt levels in pots irrigated at the lower leaching fraction. Soil salinity and individual pot leaching fractions were often highly variable and likely contributed to inconsistent leaching treatment effects.

Sorghum yields for each soil, averaged across leaching treatments, are given in Table 4. Yields in the first cropping period (February-March, 1979) were generally lower than yields of the second cropping period (August-September, 1979). Cool soil and greenhouse temperatures during February delayed sorghum germination in two of the three soils, and probably also reduced final yields. Surprisingly, plants germinated and grew well in the sandy loam soil during this same period. There was no difference in salinities among soils in the first crop. Thus, the superior crop growth in the sandy loam was apparently not related to our treatments, and was not pursued further. Indeed, relative crop growth in each salinity treatment, in each soil, was the prime concern in the study and is illustrated in Fig. 1. Relative yield was calculated by expressing the yield for any salinity treatment as a percentage of yield associated with the lowest salinity treatment.

Table 3. Effect of leaching fractions on sorghum yield for two cropping periods using various saline waters.

	Sand Loam Doak					Sand (Sheppard)					Fine Sandy Loam (Lea)				
	Irrigation Water					Irrigation Water					Irrigation Water				
Leaching Fraction	S_1#	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5
Crop 1															
Sorghum Yield at .15 L.F.†	20.3	15.5	9.3	2.3	1.0	3.7	4.9	2.5	0.6	0.7	8.5	5.5	5.2	1.5	0.7
Sorghum Yield at .30 L.F.	18.8	15.6	8.7	1.4	1.0	8.3	5.5	3.3	0.4	0.3	7.5	6.7	5.6	1.4	0.4
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop 2															
Sorghum Yield at .15 L.F.	21.2	5.9	0	0	0	22.6	4.7	0	0	0	17.3	1.8	0	0	0
Sorghum Yield at .30 L.F.	24.1	21.5	1.5	0	0	21.3	19.2	0	0	0	19.9	15.7	0	0	0
Significance	*	**	NS	NS	NS	NS	**	NS	NS	NS	*	*	NS	NS	NS

* significant at 5% level

** significant at 1% level

† mean yield/pot expressed in grams dry weight

\# S_1 = 1250 ppm; S_2 = 2500 ppm; S_3 = 5000 ppm; S_4 = 10000 ppm; S_5 = 15000 ppm, Total Dissolved Solids

Table 4. Effect of saline irrigation water on sorghum yield (Experiment one).

Irrigation Waters TDS (ppm)	Sand (Sheppard)	Sandy Loam (Doak)	Fine Sandy Loam (Lea)
		Crop 1	
1250	5.98*	19.53	6.10
2500	5.20	15.56	5.89
5000	2.87	9.00	4.74
10000	0.51	1.85	1.46
15000	0.47	1.02	0.55
	LSD @ 5% = 3.11	LSD @ 5% = 1.74	LSD @ 5% = 1.01
		Crop 2	
1250	20.65	20.14	18.58
2500	11.98	13.58	8.73
5000	0.100	0.73	0.00
10000	0.00	0.00	0.00
15000	0.00	0.00	0.00
	LSD @ 5% = 2.12	LSD @ 5% = 4.01	LSD @ 5% = 1.64

* mean yield/pot expressed in grams dry weight

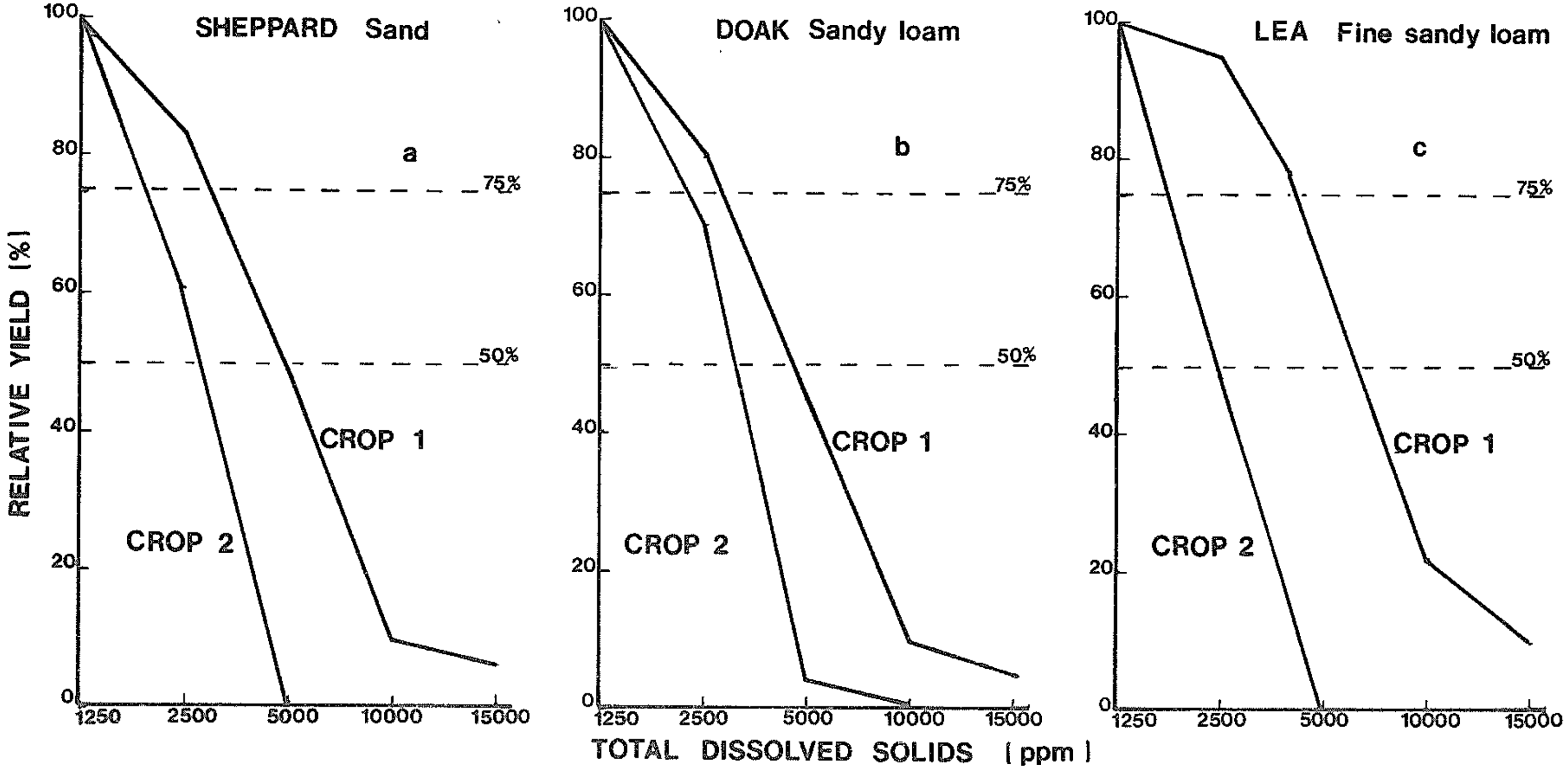

Figure 1. Effect of different concentrations of saline irrigation waters on sorghum yield. Yield is measured for: a) Sheppard sand, b) Doak sandy loam and c) Lea fine sandy loam over two cropping periods and is expressed as a percent of crops grown with the lowest salinity water.

The lower crop yields associated with the sand and fine sandy loam soils (compared to the sandy loam soil) complicates the interpretation of data from the first cropping period, but a few generalizations are possible. Sorghum yields tended to be highest in pots irrigated with the lowest salinity waters (waters S_1 and S_2). Water S_2 (TDS = 2500 ppm) had twice the salinity of S_1 (TDS = 1250 ppm), but significantly reduced sorghum yield in only the Doak sandy loam. Even in the Doak soil, yields of plants irrigated with S_2 water were 80% of the maximum yield attained.

Yields from pots irrigated with water S_3 (TDS = 5000 ppm) were usually significantly reduced relative to S_1 and S_2 treatments (Table 4). Yields of plants grown with S_3 were 46-78% of plants grown with water S_1 (Fig. 1). Water S_3 apparently represented the critical salinity for sorghum growth under the conditions of our experiment. At higher salinities (S_4 and S_5), plant yields were severely reduced, while at lower salinities (S_1 and S_2) yields were at least 80% of maximum.

Yields of pots irrigated with waters S_4 and S_5 were not significantly different from each other, but were significantly reduced below the yields in treatments S_1 and S_2. The very high salinities associated with waters S_4 and S_5 (10,000 and 15,000 ppm TDS, respectively) were apparently above the salinity tolerance of sorghum.

Results of the first cropping period suggest that waters S_1, S_2 and S_3 could be used to grow sorghum if a moderate reduction in yield (primarily associated with S_3) could be tolerated. However, soils used in this experiment were initially non-saline and probably represented only the first year or two in a field study.

The second sorghum crop was grown in the same partially salinized pots, and received saline water irrigations throughout the cropping period. Presumably because of the much warmer air and soil temperatures, early growth of germinated seeds was superior to the first winter crop (Table 4). However, germination was completely inhibited in pots irrigated with waters S_4 and S_5, and was limited in pots irrigated with water S_3.

Germination and growth was good in all soils irrigated with water S_1, (Table 4). Yields were significantly ($P = 0.05$) reduced in pots receiving water S_2, but were 47-67% of yields from treatment S_1 (Fig. 1). Pots irrigated with water S_3 yielded plants in the Doak sandy loam and in the Sheppard sand but yields were very low.

Data from the second cropping period emphasize the importance of long-term studies of salinity tolerance. Steady-state salinity profiles are usually very slow to develop in soils (Davis and O'Connor, 1980). Until the entire cropping profile is salinized, plant yields may remain high (first crop), and may not reflect the excessive salinities developing in a soil. As the entire profile becomes salinized (second crop), the germinating seed and growing plant encounters increased salinity throughout the profile to varying degrees (Appendix Fig. 3) and yields may decrease. The more saline the water, and the more water applied, the more quickly and the more severly the salinity will express itself.

Results from the second crop suggest that only waters S_1 and S_2 would be practical to grow sorghum when these waters are the sole source of irrigation water for many seasons. However, plants may respond differently under field conditions (particularly if rainfall is significant, for example see Miller, 1979), and such studies should be conducted before sole useage of saline waters is dismissed. Results of experiment one also address the practical situation of whether saline waters could be used to substitute for fresh water as the sole source of irrigation water for only 1, or possibly 2, seasons. In this case, steady-state is not expected to be attained and the results of the first cropping period may be appropriate. The data suggest that farmers could substitute waters S_1 and S_2, and possibly S_3, for fresh water when normal irrigation supplies are disrupted. Again, field studies are necessary to confirm the greenhouse studies and to identify unforeseen problems associated with the technique.

Experiment Two

The possibility of using saline waters to supplement, rather than to completely replace, fresh water irrigation was examined in experiment two. The same five saline waters used in the first experiment were used in the second greenhouse study. Three successive sorghum crops were grown in two soils (Bluepoint sand and Harvey fine sandy loam). Sorghum yields for all three crops (cropping periods) are given in Table 5. Representative, relative yield (1st and 3rd crops) data for the Harvey soil are given in Fig. 2. The reference yield used to calculate relative yields was yield of pots irrigated with only fresh water (Table 1).

As in experiment one, sorghum grown in the winter (crop one) did not yield as well as sorghum grown in the summer months (crops two and three). The low winter yields are ascribed to the lower solar radiation and cooler temperatures associated with this period. Soil salinity

Table 5. Interactive effects of saline water salt concentration and frequency of application on mean sorghum yield for three consecutive crops.

Irrigation Water (ppm TDS)	Sand (Bluepoint)				Sandy Loam (Harvey)			
	Freq. 1	Freq. 2	Freq. 3	Freq. 4	Freq. 1	Freq. 2	Freq. 3	Freq. 4
Crop 1								
Fresh water	16.7*				18.5			
1250		15.8	12.9	14.2		18.7	17.0	18.1
2500		15.4	13.5	13.0		18.4	17.4	16.1
5000		14.1	9.2	8.3		17.0	14.7	11.4
10000		12.8	7.0	3.9		15.4	11.4	6.9
15000		7.3	6.5	2.5		13.2	8.0	4.1
		LSD @ 5% = 3.33 (within Crop 1 for sand)				LSD @ 5% = 1.94 (within Crop 1 for sandy loam)		
Crop II								
Fresh water	19.66				16.76			
1250		21.5	15.0	16.3		14.1	18.0	15.0
2500		19.4	12.5	12.2		14.3	16.0	12.6
5000		20.0	9.9	2.3		10.2	16.3	9.5
10000		14.1	1.8	0.1		10.8	4.1	0.4
15000		7.0	0.6	0.3		6.9	3.0	0.2
		LSD @ 5% = 4.71 (within Crop II for sand)				LSD @ 5% = 6.65 (within Crop II for sandy loam)		
Crop III								
Fresh water	25.9				30.9			
1250		26.0	21.8	17.7		30.2	27.6	22.4
2500		23.5	19.6	11.7		22.0	20.4	18.6
5000		22.6	9.0	4.9		23.0	13.5	9.5
10000		13.3	3.9	0.3		17.5	6.2	0.3
15000		8.5	0.0	0.0		8.4	2.7	0.8
		LSD @ 5% = 5.02 (within Crop III for sand)				LSD @ 5% = 9.8 (within Crop III for sandy loam)		

*Mean yield/per pot expressed in grams dry weight

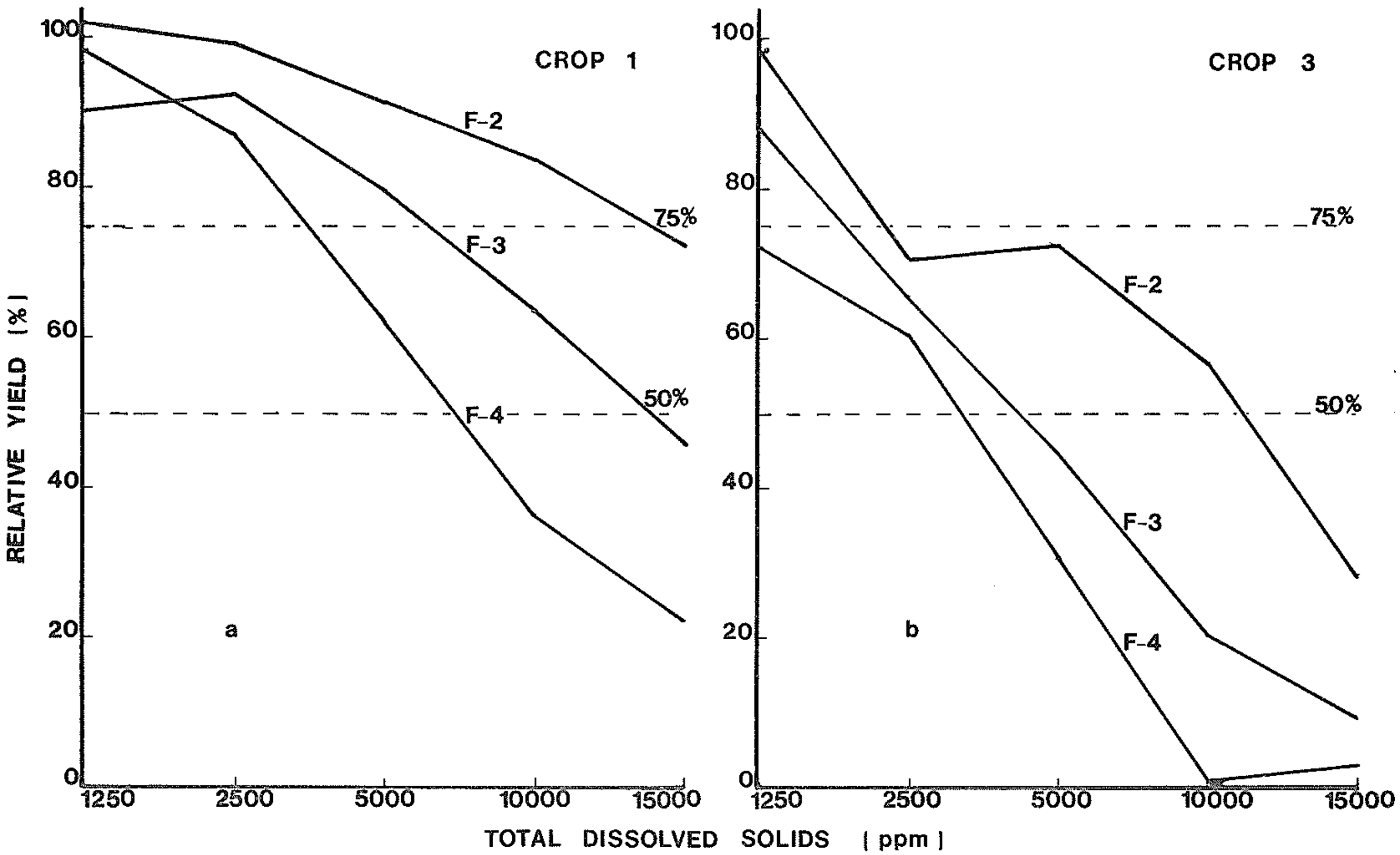

Figure 2. Interactive effects of saline irrigation waters and frequency of application on relative sorghum yield. Figure is for fine sandy loam soil (Harvey), crops 1(a) and 3(b). F-2 = 6 weeks fresh water, 2 weeks saline water; F-3 = 4 weeks fresh water, 4 weeks saline water; F-4 = 2 weeks fresh water, 6 weeks saline water.

was lowest during the first crop and was not considered to be responsible for the overall lower winter yields.

In all cropping periods, sorghum yields (Table 5) were highest in pots receiving the lowest salinity waters applied at the lowest frequencies (least amount of saline water supplement). Thus, waters S_1, S_2 and S_3 applied during the last two weeks of growth (Frequency 2) resulted in yields non-significantly different from yields in pots receiving only fresh water. As applied water salinity increased and/or the degree of supplementation (frequency) increased, yields tended to decrease.

In the first crop, there was no statistically significant effect on yield in either soil from using water S_1 at any frequency; from using water S_2 at frequency 2 or 3 (two or four weeks supplementation); or from using water S_3 at frequency 2.

Plants growing in the Harvey fine sandy loam appeared to resist water stress between weekly irrigations better than plants growing in the Bluepoint sand. To minimize this difference between soils, more frequent irrigations were instituted later in the experiment. Nevertheless, data for the Harvey soil may more realistically reflect salinity treatments than the Bluepoint soil. Thus, relative yield data for the Harvey soil are emphasized here (Fig. 2). Statistics aside, the data of Fig. 2a suggest that reasonable (75% maximum) sorghum yields were obtained in the first crop with waters S_1, S_2, S_3, and S_4 at frequency 2, with waters S_1, S_2, and S_3 at frequency 3, and with waters S_1 and S_2 at frequency 4. Thus, even water containing 10,000 ppm TDS could be used the last two weeks of the growth period, or water containing 5,000 ppm TDS could be used for one-half (4 of 8 wks) of the growth period without severely reducing yields. Water S_2 could be used to grow sorghum at realistic yields if preceded by a 2 week germination and growing period during which fresh water is applied.

Soil salinity increased during the first crop in proportion to the salinity and amount (frequency) of saline water applied (Appendix Figs. 4 and 5). Leaching (LF = .20) was performed between cropping periods with fresh water. Soil salinity at the 10cm depth (midpoint) decreased in response to leaching, but was higher at the initiation of crops 2 and 3 than at the initiation of crop 1. The higher initial and more rapid increase in soil salinity in crop 2 compared with crop 1 is reflected in the yield data of crop 2 in Table 5. Low salinity waters applied at low frequencies tended to maintain high yields, but yields of pots irrigated with waters S_4 and S_5 applied at frequencies 3 and 4 decreased dramatically. As soil salinity increased from the initially non-saline conditions of crop one, sorghum plants could tolerate less salinity additions before exhibiting lower yields.

Yield trends from crop 3 were very similar to yield trends from crop 2 and suggested more or less steady-state conditions. Such data may represent the effects of a longterm irrigation program of supplementing fresh water with various saline waters. The data in Table 5 (crop 3) and Fig. 2b suggest the following conclusions for both soils:

1) water S_1 could be used to supplement fresh water at all frequencies without significantly ($p = 0.05$) reducing sorghum yields,
2) water S_2 could be used for at least two, and probably four weeks of the 8 week growth period and still maintain 65-75% maximum yields,

3) water S_3 could be practically (economically) used to supplement fresh water irrigation only at the end of the growth period (frequency 2),

4) waters S_4 and S_5 are apparently too saline to use for long periods as even a minor supplement to fresh water.

Again, it is important to emphasize that these conclusions are based on greenhouse data where no rainfall was present. Rainstorms, particularly winter (off season) rains can be very effective in leaching salts from soils and may allow surface soils to start the season desalinized. Another common situation is for fresh water supplies to be abundant early in the irrigation season and to be applied heavily as pre-season irrigations. If saline waters are used as supplements to fresh water under the above conditions, plant yields could be higher than observed herein. The beneficial effects, however, are expected to be limited to situations involving waters S_1, S_2, and possible S_3. Waters S_4 and S_5 are too saline and contain too much Na^+ to be beneficially affective in most cases. In fact, even small additions of high quality fresh water to most soils equilibrated with waters S_4 and S_5 will result in severe dispersion of the soil surface and severely reduced permeabilities (Park and O'Connor, 1980). Extensive use of amendments (gypsum, sulfuric acid) would be necessary to reverse permeability reductions. Very sandy soils (e.g. Bluepoint sand) can tolerate the dispersive mechanism, but plant yields would likely be very low with such waters in any case.

SUMMARY AND CONCLUSIONS

New Mexico and many other parts of the world have vast supplies of underground waters of various salinities. Using these supplies to totally replace or to extend fresh water supplies for irrigation could have tremendous social, political and agricultural implications. Research involving saline water has been conducted for decades but has often been restricted in generality. The research reported here was intended to address the question of whether saline waters similar to New Mexico's groundwaters could be used to irrigate a commonly grown crop in soils common to the state. Further, the approach was designed to simulate practical use conditions in New Mexico irrigated agriculture.

The first experiment addressed the situation of total reliance on saline waters varying in TDS from 1,250-15,000 ppm. Greenhouse data suggest that only water S_1 (1,250 ppm) and possibly water S_2 (2,500 ppm) could support reasonable sorghum yields over the long term. More saline waters (e.g. S_3 - 5,000 ppm) supported reasonable yields initially but yields decreased dramatically in the second "season". Field data are needed to confirm the greenhouse results and to identify the length of time such saline water substitutions can continue before excess salinity reduces yield. Salinity buildups were artifically fast in the greenhouse study and may not be duplicated in the field for several years.

The greenhouse data suggest that the most reasonable scheme for saline water utilization is as a supplement to fresh water supplies. Fresh water would be used to germinate the crop and for varying periods (2-6 wks) thereafter before saline water is introduced. Given this procedure, water S_1 supported (long-term) sorghum yields non-significantly different from that of sorghum grown with only fresh water. Water S_2 could be used for half of the growth period and water S_3 for ¼ the growth period without seriously reducing yields. In the first year of such saline water utilization, the limits of water salinity and degree of supplementation could be expanded even more.

Inherent to the discussion above is the subjective evaluation of an "acceptable" yield. Farmers, of course, try to maximize yields and would ordinarily choose fresh water for irrigation. When conditions necessitate poorer quality water utilization the tolerated (reduced) yield will determine how saline a water can be used.

Another limitation to the above discussion is that all data are for sorghum. Sorghum is described as a moderately salt tolerant crop (USSL, 1954) and was chosen for this purpose. More salt tolerant crops (cotton, established alfalfa) could be expected to extend the limits of salinity and frequency given above. This would likely be of greatest effect in determinations of whether, and how, to use waters S_2 and S_3. Waters S_4 and S_5 are not likely to be of practical use for any common agricultural crop.

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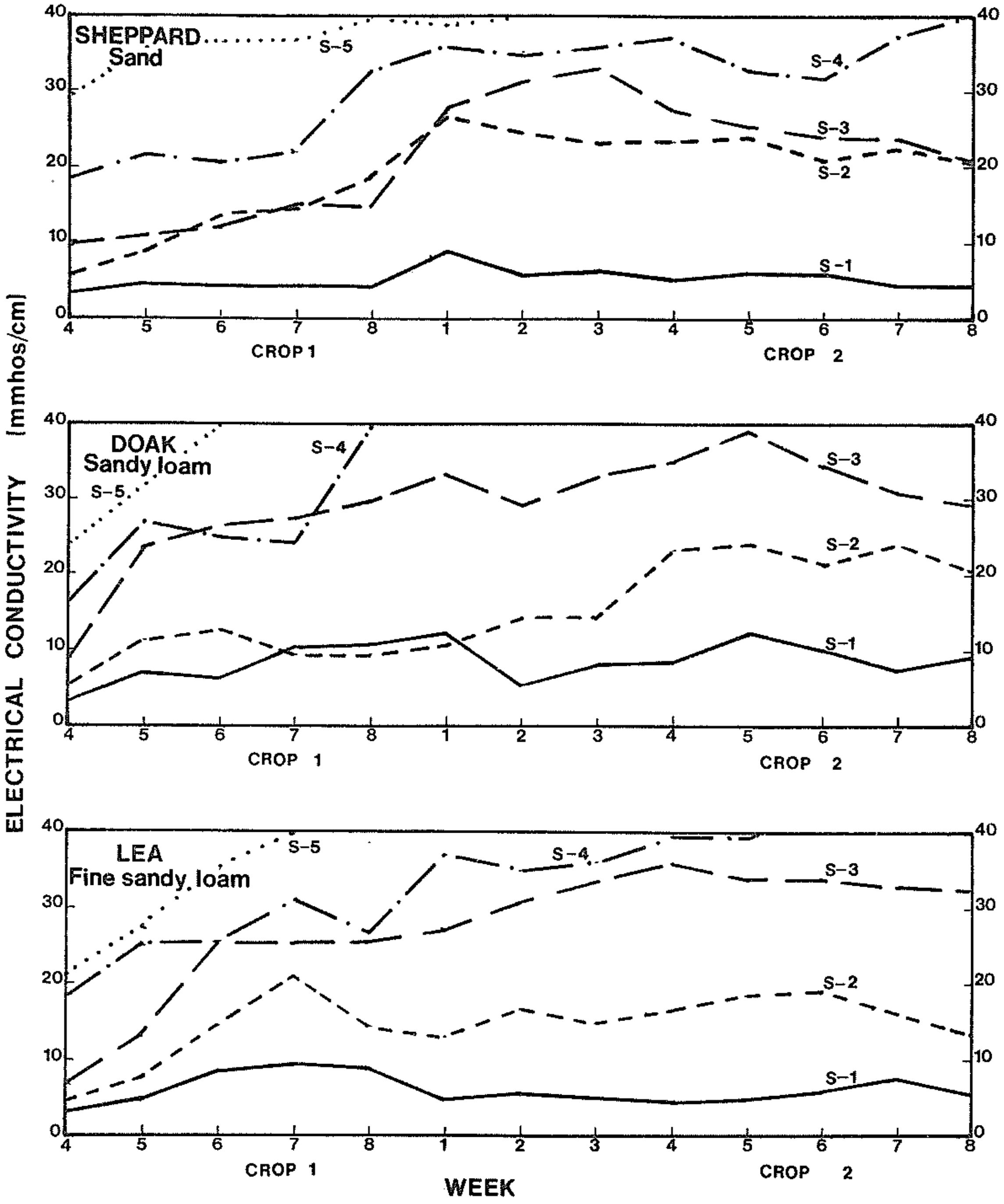
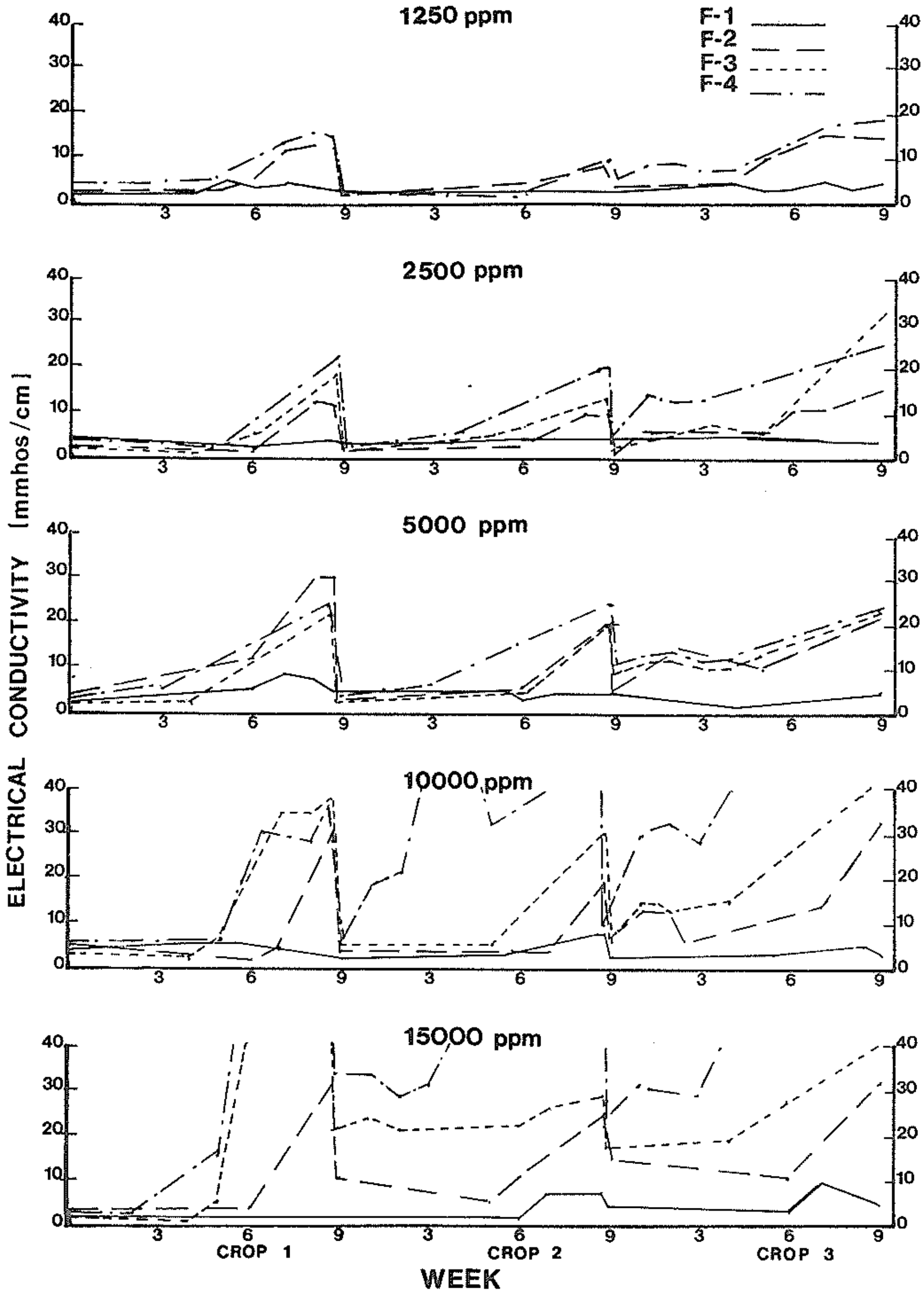
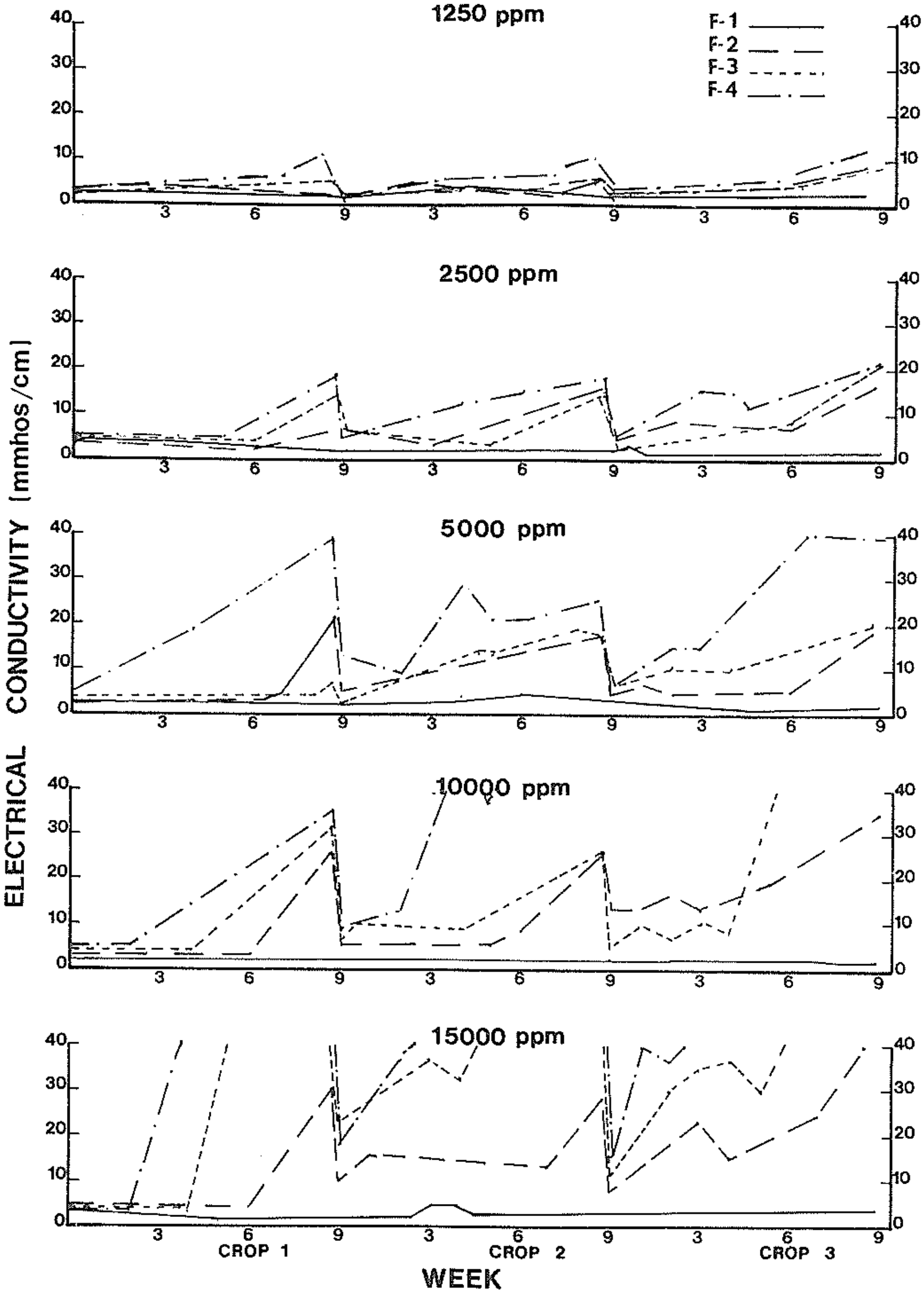
APPENDIX



Appendix Figure 1. Soil electrical conductivity (at 10 cm. depth) as a function of saline concentration of irrigation water applied to three soils, experiment 1.
S-1 = 1250 ppm TDS; S-2 = 2500 ppm TDS; S-3 = 5000 ppm TDS;
S-4 = 10000 ppm TDS; S-5 = 15000 ppm TDS



Appendix Figure 2. Soil electrical conductivity (at 10 cm. depth) as a function of frequency and water salinity on Bluepoint sand. *F-1 = 8 weeks fresh water; F-2 = 6 weeks fresh water and 2 weeks saline water; F-3 = 4 weeks fresh water and 4 weeks saline water; F-4 = 2 weeks fresh water and 4 weeks saline water.



Appendix Figure 3. Soil electrical conductivity (at 10 cm. depth) as a function of frequency and water salinity on Harvey sandy loam. *F-1 = 8 weeks fresh water; F-2 = 6 weeks fresh water and 2 weeks saline water; F-3 = 4 weeks fresh water and 4 weeks saline water; F-4 = 2 weeks fresh water and 6 weeks saline water.