SORGHUM YIELD AS INFLUENCED BY WATER QUALITY, LEACHING FRACTION AND ITS CO-RELATION WITH INDICES OF SALINITY

Muhammad Yasin*, Shah Muhammed and Abdul Rauf*****

ABSTRACT

The experiment reported in this study was carried out in lysimeters filled with normal loam soil and sorghum was grown under nonsteady and steady-state. Irrigation was given with 12 synthetic waters having three EC levels (2,3 & 4 mS/cm) two SAR levels (10 and 15) and two RSC levels (2.5 and 5) maintaining low and high leaching regimes (LF). The dry matter yield of sorghum under nonsteady-state decreased with the increase in EC,SAR and RSC of irrigation water, whereas under steady-state, the yield only decreased with increasing SAR and RSC of irrigation waters. The beneficial effect of LF was clearly observed as increasing LF increased the dry matter yield of sorghum for both the years at all salinity levels of irrigation waters. Out of 12 indices tested, the sorghum yield under nonsteady-state related to only 4 indices of salinity, best correlation being with average profile salinity, while the crop under steady-state related to 5 indices of salinity, most of which account for average profile salinity or salinity of the bottom root zone.

INTRODUCTION

Soil Salinity is an important environmental factor in which plants grow. Salinity problems are known to exist in many soils throughout the world, particularly in arid and semi-arid regions, where irrigation waters contain more salts than are removed by crop. Continuous irrigation with such waters without proper leaching progressively salinises the soil. If concentration of the salts becomes excessive, crop yields are reduced because of decrease in osmotic potential of soil water. To prevent harmful accumulation of salts, the soil profile must be leached periodically with an amount of water in excess of that used for evapotranspiration.

Under field conditions, soil water salinity geneally ranges from a low level at the surfact to high levels at the bottom of the root zone, depending on leaching fractions (LF) and irrigation methods. Crop salt telerance data, obtained with uniform salinity distributions, are only applicable to such nonuniform salinity distributions under field conditions with the assumption that the plants respond to average soil water salinity, irrespective of its distribution in the root zone (Rhoades, 1974). Some findings support this assumption (Bower et al. 1970), while others have demonstrated that variations in salinity distribution in the root zone influence the crop response (Bingham and Garber, 1970).

Bernstein and Francois (1973) concluded that

* Assistant Agricultural Chemist, Soil Salinity Research Institute, Faisalabad.
** Professor, Department of Soil Science, University of Agriculture, Faisalabad.
*** Assistant Professor, Department of Soil Science, University of Agriculture, Faisalabad.

crop response was better related to upper root zone salinity and it was little affected by deep root zone salinity. In contrast to the above, Eaton (1966) concluded that the salinity of the root zone as a whole must be taken into account. Rhoades and Merrill (1976) also concluded that plant response correlated better with the average root zone salinity. The present study was under-taken: (i) to determine the effect of saline-sodic waters on plant growth and yield under nonsteady-state and steady-state at different LFs; (ii) to evaluate the effect on plant growth of nonuniform salinity distribution with depth and to relate it to various indices of soil salinity.

MATERIALS AND METHODS

The experiment was conducted in cement pipe lysimeters with crops grown in the sequence of berseem and sorghum. The lysimeters,60 cm in length and 22.5 cm in diameter were filled with nonsaline loam soil of pH = 8.0,EC x 10^3 = 2.6,SAR = 2.2 $(mmol/1)^{1/2}$,ESP = 2.8 and CEC of 10.1 me/100 g. The lysimeters had an out lets at the bottom for drainage. Cultivar, JS–1 of sorghum (sorghum bicolor) was sown in lysimeters on June 16, 1977. After germination, the plants were established by irrigating with canal water for about 3 weeks. Thinning to 8 plants per lysimeter was done before irrigation with synthetic waters was initiated. Twelve synthetic waters having 3 EC levels (2,3, and 4 mS/cm),2SAR levels (10 & 15) and 2 RSC levels (2.5 and 5.0) were prepared by dissolving salts, $NaHCO_3$, Nacl, Na_2 So_4, $CaCl_2$ and $MgSo_4$ in canal water (Table–I). Moreover two LFs of each water as given in the results and discussion were applied. As far as possible, the amount of water applied at each irrigation was equal to that evapotranspired during the previous irrigation cycle plus that required to achieve the desired LF, according to the equation of van Schilfgaarde et al.(1974): $V_{iw} = V_{cu}/1-LF$.

At each irrigation, nutrients were added at the rate of 2ml of stock solution per elapsed day since the previous irrigation. Nutrients were applied in the last portion of irrigation water to avoid their leaching. One ml of stock solution containe in me: 1.25 of K, 2.8 of NH_4, 1.0 of No_3, 0.25 of H_2 PO_4 and 2.8 of So_4. The leachate from each irrigation was measured and analysed occasionally for EC, Na, Ca + Mg and Cl to mointor progress towards steady-state. The crop was harvested at earing stage on August 31, 1977 and weight of oven dry matter (60 ^oC) recorded. The first crop of sorghum represnted plant growth under nonsteady-state, because soil and water had not achieved steady-state by the time of harvesting of crop (Fig 1 & Fig 2). After harvesting sorghum, the uncropped soil was irrigated regularly with the same synthetic waters for about one month. During rainfall lysimeters were covered with plastic sheets. Then berseem was grown and irrigated with the same saline-sodic waters. The steady-state was achieved during its growth period. After harvesting berseem, sorghum cultivar, JS–1 was sown on April 28, 1978 and harvested on August 9, 1978 at earing stage. The LFs attained were 0.051 and 0.103 for waters of EC 2 mS/cm, 0.075 and 0.141 for waters of EC3 mS/cm and 0.099 and 0.188 for waters of EC 4 mS/cm. The second crop of sorghum represented plant growth under steady-state.

On completion of the experiment, soil colum in each lysimeter was sectioned into 4 equal segments of 11 cm each and analysed by procedures described by U.S. Salinity Laboratory Staff (1954). The crop yield was correlated with various indices of soil salinity. All treatments were in duplicate making a total of 51 lysimeters including 3 control pipe lysimeters.

RESULTS AND DISCUSSION

Sorghum yield under nonsteady-state.

Maximum dry matter yield of sorghum under nonsteady-state was obtained in case of control (canal water) and it decreased with increasing salinity of irrigation water (Table 2). The yield reduction compared with control was 30.9, 44.4 and 48.2% when irrigated with waters of EC 2,3 and 4 mS/cm,

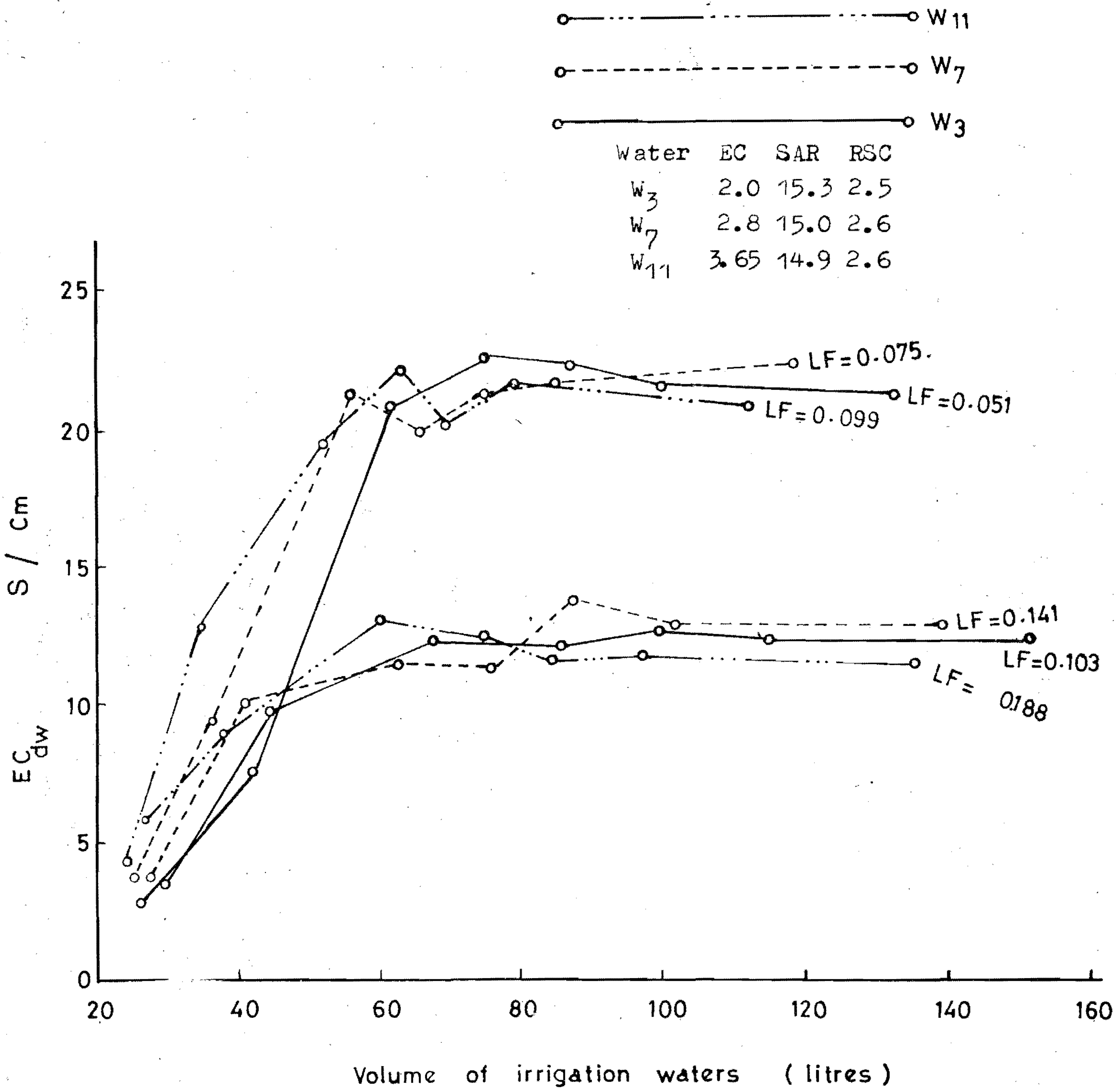

Fig. 3. Effect of quality of irrigation water and LF on EC_{dw} at different sampling periods

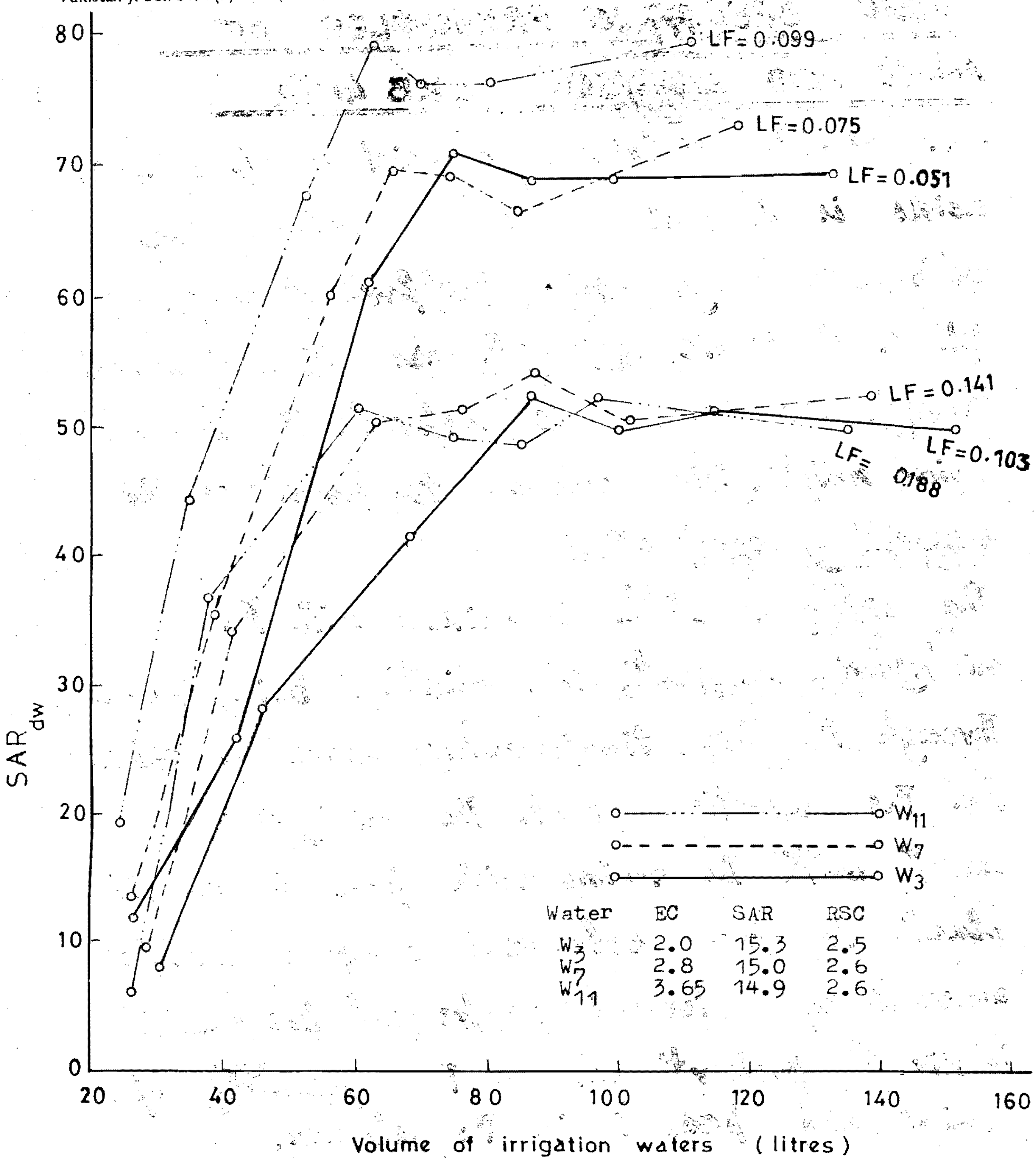

Fig Effect of irrigation water quality and LF on SAR_{dw} at different sampling periods

TABLE – 1

CHEMICAL COMPOSITION OF SYNTHATIC SALINE-SODIC WATERS WITH RESIDUAL SODIUM CARBONATE.

Water No.	EC x 10^3	Ca+Mg	Na	HCO_3	Cl	So_4	RSC	SAR_{iw}	SAR^*_{adj}	PH_c**
		me/l								
W_1	1.90	4.7	15.3	7.2	6.4	6.4	2.5	10.0	18.8	7.12
W_2	1.85	4.5	15.0	9.4	5.1	5.0	4.9	10.0	19.7	7.03
W_3	2.00	2.7	17.8	5.2	7.5	7.8	2.5	15.3	22.8	7.53
W_4	1.90	2.6	17.4	7.6	6.2	6.2	5.0	15.3	25.1	7.36
W_5	2.85	8.8	21.7	11.2	9.6	9.7	2.4	10.3	23.6	6.71
W_6	2.75	8.8	20.7	13.8	7.9	7.8	5.0	9.9	23.5	6.62
W_7	2.80	5.4	24.6	8.0	11.0	11.0	2.6	15.0	28.9	7.07
W_8	2.75	5.2	24.3	10.4	10.0	9.1	5.2	15.1	30.6	6.97
W_9	3.70	13.9	27.1	16.4	12.1	12.5	2.5	10.3	26.9	6.39
W_{10}	3.65	13.7	26.3	18.8	10.5	10.7	5.1	10.0	26.7	6.33
W_{11}	3.65	8.8	31.2	11.4	14.1	14.5	2.6	14.9	33.7	6.74
W_{12}	3.60	8.5	31.2	13.4	13.3	13.9	4.9	15.1	35.0	6.68

*SAR_{adj} = SAR_{iw} $[1+(8{,}0-pH_c)]$, where pH_s = 8.0

**pH_c = $PK_2-PK_c + p(Ca+Mg) + p(Co_3 + HCO_3)$, (Bower et al., 1965).

TABLE–2.

EFFECT OF IRRIGATION WATER QUALITY AND LF ON DRY MATTER YIELD OF SORGHUM (G/LYSIMETER).

Treatments	LF	1977 crop	LF	1978 crop
Control (canal water)		231.4		233.3
EC x 10^3				
2		141.5		126.4
3		128.5		137.9
4		119.8		126.2
SAR				
10		144.2		143.4
15		115.7		116.9
RSC, me/l				
2.5		144.4		136.4
5.0		115.5		124.0
EC x 10^3	LF		LF	
2	0.096	126.1	0.051	117.9
	0.15	156.8	0.103	134.9
3	0.12	113.5	0.075	128.6
	0.18	143.6	0.141	147.2
4	0.14	114.4	0.099	114.8
	0.19	125.0	0.188	137.7

Comparison of means of significant parameters.*

SAR	10	15	10	15
Means	144.2	115.7	143.4	116.0
RSC	2.5	5.0		
Means	144.4	115.5		

* = all other factors like EC/LF are non-significant.

TABLE–3.

CORRELATION AND REGRESSION ANALYSIS RELATING SORGHUM (1977 CROP) DRY MATTER YIELD TO VARIOUS INDICES OF SALINITY.

Index of salinity[a/]	Correlation	Regression equation
	Irrigation water salinity parameters	
1. EC_{iw}	– 0.994 NS	–
2. Effective salinity, me/l (Eaton, 1954).	0.398 NS	–
3. Effective salinity, me/l (Doneen, 1954)	– 0.484 NS	–
	Average profile salinity parameters	
1. Mean soil salinity (Eaton, 1954)	– 0.374 NS	–
2. Average profile salinity (Ingvalson et al., 1976)	– 0.384 NS	–
3. Average EC_e of soil profile	– 0.606*	Y = 248.57 – 13.94 x
4. Average root zone salinity (Rhoades and Merrill, 1976)	– 0.394 NS	
	Bottom salinity parameters	
1. EC of bottom soil quarter	– 0.437*	Y = 191.02 – 4.42 x
2. EC_{dw}	– 0.346 NS	–
3. $EC_{dw}/2$ (van Schilfgaarde et al., 1974)	– 0.343 NS	–
	Water Uptake weighted parameters	
1. Calculated mean salinity (Bernstein and Francois, 1973)	– 0.407*	Y = 190.94 – 8.74 x
2. Weighted root zone salinity (Oster and Rhoades, 1977)	– 0.452*	Y = 190.03 – 5.13 x

_a/ = Units of indices of salinity are mS/cm except those mentioned.

* = Significant at 5% level.

NS = Non–significant.

TABLE–4

CO-RELATION AND REGRESSION ANALYSIS RELATING SORGHUM (1978 CROP) DRY MATTER YIELD TO VARIOUS INDICES OF SALINITY.

Index of salinity a/	Correlation	Regression equation
Irrigation water salinity parameters		
1. EC_{iw}	–0.008 NS	–
2. Effective salinity, me/1 (Eaton, 1954)	–0.125 NS	–
3. Effective salinity, me/1 (Doneen, 1954)	–0.183 NS	–
Average profile salinity parameters		
1. Mean soil salinity (Eaton, 1954)	–0.421*	Y = 167.47 – 5.645x
2. Avg. profile salinity (Ingvalson et al., 1976)	–0.389 NS	
3. Avg. EC_e of soil profile	–0.564*	Y = 212.53 – 9.675x
4. Avg. root zone salinity (Rhoades and Merrill, 1976)	–0.394 NS	
Bottom salinity parameters		
1. EC_e of bottom soil quarter	–0.608*	Y = 193.77 – 4.598x
2. EC_{dw}	–0.401*	Y = 166.03 – 2.236x
3. $EC_{dw}/2$ (van Schilfgaarde et al., 1974)	–0.401*	Y = 165.89 – 4.450x
Water Uptake weighted parameters		
1. Calculated mean salinity (Bernstein and Francois, 1973)	–0.191 NS	–
2. Weighted root zone salinity (Oster and Rhoades, 1977)	–0.350 NS	–

a/ = Units of indices of sulinity are mS/cm except those mentioned.

* = Significant at 5% level.

NS = Non-significant.

respectively. The yield of sorghum decreased significantly by increasing SAR values of irrigation waters. The decrease in yield may be due to accumulation of exchangeable Na in soil or Na may be directly toxic to sorghum plants (Rhoades, 1972). Nutritional imbalance (Bernstein, 1974) due to high exchangeable Na may also result in poor crop yield.

The RSC of water also significantly decreased the yield of sorghum. Maximum yield of 144 g/lysimeter was obtained at RSC value of 2.5 and it decresed significantly to 115 g/lysimeter with increase in RSC value to 5.0 me/1. The decrease in yield at higher level of RSC seems due to toxicity of high bicarbonates in irrigation water or due to upsetting of the nutritional balance. Plant roots show reduced respiration in the presence of bicarbonate ions, the excess of which inhibit the activity of cytochrome oxidase (Miller, 1959).

The positive response of sorghum yield to LF under each salinity level was quite prominent. The LF increased approximately in proportion to increase in salinity of water. Equivalent LFs (designated as LF/EC_{iw} in mS/cm) were found to be statistically nonsignificant. Yield decreased markedly with decreasing LF except with water of EC 4 mS/cm, where the decrease was small compared with high LF. Higher LF minimizes the accumulation of salts and exchangeable Na in the soil, while low LF reduces the salts in drainage water, maximizes the precipitation of sparingly soluble salts (Rhoades et al. 1973). The SAR value of soil solution at low LF increased and thereby yield was reduced (Rhoades and Merrill, 1976). As LF has a marked effect on salinity of soil, it can reduce deleterious effect of water for successful crop production.

Sorghum yield under steady-state:

Maximum dry matter yield (Table 2) of sorghum under steady-state was 233.3 g with canal water and it decreased drastically with saline-sodic waters. The difference in yield among various salinity levels was small because proportionately higher LF values were used for more saline water. With increasing salinity levels, sorghum yield decreased continuously in 1977, under nonsteady-state but the trend was not similar after achieving stady-state in 1978. Perhaps the higher LF employed, modified the adverse effect of more saline water by controlling salts in the root zone and the deeper plant roots were exposed to almost similar soil salinity levels. The data (Table 3 & 4) showed that sorghum crop responded relatively more to water uptake weighted salinity parameters in 1977, than in 1978 and more to bottom salinity in 1978 than in 1977. This is probably due to the reason that under steady-state the salinity at the bottom of the root zone reached higher values wheich better represented the soil profile salinity then those under nonsteady-state.

Analysis of variance showed that there was a significant reduction in sorghum yield with increasing SAR of irrigation water. This trend is similar to that of the previous sorghum crop. The increasing SAR_{iw} from 10 to 15 reduced sorghum yield from 143 to 116.9 g/lysimeter. The higher RSC value of irrigation water though reduced sorghum crop yield, yet the difference in yield between low (2.5 me/1) and high (5.0 me/1) RSC values of water was statistically nonsignificant. There was drastic reduction in yield with both RSC values compared with control. The lower yield at higher RSC value may be due to more precipitation of Ca and Mg as insoluble salts from water and proporationate increase of exchangeable Na in soil.

Higher yield was evident at higher LF, because it not only controlled EC, but the soil ESP as well (Rhoades, 1968) within limits which increased sorghum yield. The yield trend pertaining to LF is similar to that of the previous crop. It appears that the adverse effects of increase salinity of irrigation water can be minimized by increasing LF so that the average salinity and sodicity of root zone was not allowed to increase beyond certain limits.

Correlation and Regression analysis of crop yields to various indices of salinity.

The relative effect of irrigation and soil water salinity on crop yield was examined in more detail by corre lation and regression analysis. For this purpose, following indices were tested:–

(A) Irrigation Water Salinity Parameters:

1. EC_{iw}, mS/cm.
2. Effective salinity (Eaton, 1954) me/1 = Cl + 1/2 So_4.
3. Effective salinity (Doneen, 1954) me/1 calculated by substracting $CaCo_3$, $Ca(HCO_3)^2$, $MgCo_3$ and $CaSo_4$ in that order from total concentration.

(B) Average Profile Salinity Parameters:

1. Mean Soil Salinity (Eaton, 1954) = $[(Cl+1/2SO_4)_{iw}+(Cl+1/2SO_4)_{dw}]/2$
2. Average profile salinity (Ingavalson et al., 1976) = $(EC_{iw}+EC_{dw})/2$
3. Average EC_e, mS/cm.
4. Average root zone salinity (Rhoades and Merrill, 1976). $EC_e = 0.2\ EC_{iw}\ (1+1/LF)$.

(C) Bottom Salinity Parameters:

1. EC_e of bottom soil quarter, mS/cm.
2. EC_{dw}, mS/cm.
3. $EC_{dw}/2$ (van Schilfgaarde et al., 1974), mS/cm.

(D) Water Uptake Weighted Parameters:

1. Calculated mean salinity (Bernstein and Francois, 1973) C =iw/(1-LF) in LF.
2. Weighted average root zone salinity (Oster and Rhoades, 1977). EC = 0.2 EC_{iw} [(1+1/0.64 + 1/0.37 + 1/0.19 + 1/0.10)] = $EC_{iw}(4.11)$ for LF = 0.1.

The dry matter yield of sorghum under nonsteady-state was significantly related (Table 3 to average EC_e of soil profile (r = 0.606), EC_e of bottom soil quarter (r = 0.437), calculated mean salinity of Bernstein and Francois(r = 0.407) and weighted root zone salinity of Oster and Rhoades(r = 0.452).

Correlation and regaression equations relating dry matter yield of sorghum under steady-state to various indices of salinity are presented in (Table 4). Irrigation water salinity parameters gave non-significant corrleation indicating that crop yield was not related to EC of irrigation water and effective salinity of irrigation water calculated by Eaton (1954) and Doneen (1954) under steady-state. According to Eaton (1954), the carbonates and bicarbonates do not contribute to soil salinity as these are precipitated from soil solution due to its concentration by evaporrans-piration and the sulphates are half as hazardous as equivalent amount of chlorides. Doneen (1954) considers the quantitative precipitation of $CaCo_3$, $MgCo_3$ and $CaSO_4$ from irrigation water after application to soil. These data indicated that crop yield was not directly related to irrigation water salinity parameters, other factors like LF and soil salinity were more important for controlling the crop yield. The correlation improved with average profile salinity parameters confirming further that crop yield was influenced dominantly by average profile salinity than by other indices of salinity.

Out of 4 criteria of average profile salinity, the observed average EC_e of soil profile gave relatively high value of r(–0.564). The mean soil salinity of Eaton (1954) which gave significant correlation (r = 0.421) again eliminates carbonate and bicarbonate in irrigation and drainage waters because of reasons given above. The two equations of Ingavalson et al. (1976), and Rhoades and Merrill (1976), which gave significantly low values of r(–0.389 & –0.394) account for precipitation of relatively insoluble salts from concentrated soil solutions as a result of evapotranspiration. Salinity of bottom soil quarter gave the best correlation coefficient of –0.608 indicating the importance of salinity of the bottom of the root zone for controlling crop yield. This also underscores the importance of LF for controlling salinity of soil profile. The correlation between both $EC_{dw}/2$ (van

Schilfgaarde et al., 1974) and sorghum yield was only 0.401. The equation of van Schilfgaarde also accounts for precipitation of slightly soluble salts as it is derived from EC_{dw}. The equations of Bernstein and Francois (1973), and Oster and Rhoades (1977) did not show significant r values, inspite of the fact that good coorelation was obtained between observed average EC_e of soil profile and that calculated by equation of Oster and Rhoades (1977). Both the equations take care of expected precipitation from soil solution and dissolution of soil minerals. In addition, the equation of Oster and Rhoades (1977) gives due consideration to weighted root zone salinity based on water uptake and leaching of salts from different parts of root zone. It can be concluded from the above discussion that average profile salinity or salinity of the bottom root zone control the yield of sorghum under steady-state. The results do not agree with the findings of Bernstein and Francois (1973) which indicated that crop response was better related to upper root zone salinity and or irriagtion wate salinity. This work, as well as that of Bower et al.(1970) supports the assumption that the crop response was related to mean salinity and was also affected by deep root zone salinity.

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