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EFFECT OF SALINITY AND SAR OF IRRIGATION WATER ON YIELD, PHYSIOLOGICAL GROWTH PARAMETERS OF MAIZE (*ZEA MAYS* L.) AND PROPERTIES OF THE SOIL

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Abstract: A study was conducted to evaluate the effect of salinity and SAR of irrigation water on the growth, yield, physiological growth parameters and properties of the soil. Total nine treatment combinations having different EC_{iw} (2, 4 and 6 dS m^{-1}) and SAR_{iw} [10, 15 and 20 (mmol $L^{-1})^{1/2}$] levels were applied to polythene-cemented pot containing 15-kg loamy soil. It was observed that whole of the soil profile attained EC_e > 4.0 dS m^{-1} (with all the levels of EC_{iw} and SAR_{iw}) and SAR values > 13.3 [with EC_{iw} 6 dS m^{-1} and SAR 20 (mmol $L^{-1})^{1/2}$] which are the upper limits for saline-sodic soils. Height and biomass yield, relative growth rate (RGR), net assimilation rate (NAR) and relative leaf growth rate were depressed with EC_{iw} and SAR_{iw}. However, the effect of these water quality parameters were more pronounced on growth parameters at higher than that at lower levels of EC_{iw} and SAR_{iw}. Results divulged that maize variety Sultan could tolerate EC_{iw} up to 2.0 dS m^{-1} and SAR_{iw} up to 10 (mmol $L^{-1})^{1/2}$.

Keywords: EC_{iw}, SAR_{iw}, Maize,Growth, Yield, Physiological Growth Parameters.

INTRODUCTION

Profitable agriculture in arid and semi-arid regions is mainly dependent on the fair availability of good quality irrigation water. Fresh surface water supplies in these areas are gradually becoming short to meet the crop water requirement. To augment the inadequate water supplies the use of poor quality ground water is imperative. Unfortunately, the major portion of this water (75%) is brackish/ unfit for irrigation due to variable amounts of sodium and bicarbonate ions [Malik *et al.* 1984].

Continuous and prolong use of brackish groundwater could induce salination/sodication of soils and greatly hamper the growth of most of the agronomic crops [Singh *et al.* 1992]. The proper utility of poor quality groundwater is possible only either through reclamation or by making the plants physiologically adapted to saline environment. To make the plants best suitable for saline agriculture, it is essential to study the physiological behavior of plants under the saline conditions. Maize (*Zea mays* L.) is an important crop of the country and is grown for fodder and grain purposes. It is a relatively sensitive to saline irrigation water showing 50 % reduction in yield at EC_{iw} 3.9 dS m^{-1} [Ayres and Westcot 1985]. According to a report maize is sensitive at early stages but could withstand at later growth stages to saline irrigation water [Shirazi *et al.* 1971].

Sufficient work does not seem to have been focused on the physiological behavior of maize to salinity and SAR of irrigation water, since most of the research has been centered on salt build up in soils and their subsequent detrimental effects on growth and yield. In the present investigations, height and fresh biomass yield and some derived physiological growth parameters such as relative growth rate (RGR), net assimilation rate (NAR) and relative leaf growth rate (RLGR) were taken as indicator to determined the tolerance of maize against salinity and sodium adsorption ratio (SAR) of irrigation waters.

MATERIALS AND METHODS

The investigations reported here were conducted in net-house, Institute of Pure and Applied Biology, Bahauddin Zakariya University, Multan during 2000. Surface soil (0-15 cm) in bulk was collected from the normal field. The soil was air-dried, ground, passed through a 2 mm sieve and thoroughly mixed. The physio-chemical analysis of soil showed that it was loamy in texture (sand 38.36 %, silt 46.36 % and clay 15.28 %) and had EC_e 1.52 dS m^{-1}; CO_3^{2-} nil; HCO_3^- 8.7 mmol L^{-1}; Cl^- 3.15 mmol L^{-1}; Ca^{2+} + Mg^{2+} 8.3 mmol L^{-1}; Na^+ 6.9 mmol L^{-1}; SAR 3.39 (mmol $L^{-1})^{1/2}$; organic matter 0.60 %. Cemented pots lined with polyethylene sheet were filled with this soil @ 15 kg per pot. Three levels each of EC_{iw} and SAR_{iw} @ 2, 4 and 6 dS m^{-1}; 10, 15 and 20 (mmol $L^{-1})^{1/2}$, respectively were used. Total nine waters having different EC_{iw} and SAR_{iw} combinations including one as a control (best available water at the experimental site: EC_{iw} 0.91 dS m^{-1} and SAR_{iw} 2.15) were investigated and are shown as below:

Water #	EC (dS m^{-1})	SAR (mmol $L^{-1})^{1/2}$
W0	0.91	2.19
W1	2.00	10.00
W2	2.00	15.00
W3	2.00	20.00
W4	4.00	10.00
W5	4.00	15.00
W6	4.00	20.00
W7	6.00	10.00
W8	6.00	15.00
W9	6.00	20.00

Fifteen seeds of maize variety Sultan were sown in each pot on April 29, 2000. The plants were thinned out to four in each pot 15 days after germination. The N, P and K were applied @ 80, 50 and 50 kg ha^{-1} as urea, single superphosphate and potassium sulphate, respectively. All the N, P and K were applied at the sowing of seeds. The pots were irrigated according to the crop requirement. For each irrigation, calculated amount of salts (NaCl, Na_2SO_4, $CaCl_2$ and $MgSO_4$) were dissolved in tube well water (EC 0.91 dS m^{-1}; SAR 2.15 (mmol $L^{-1})^{1/2}$; RSC 0.5 $mmol_c$ L^{-1}) and were applied to respective pots. Four harvests were taken during the experiment. First harvest was made 25-days after sowing and then 10-days interval was fixed. At the time of each harvest, four plants from each pot were taken and three replications were left out for recording height and fresh biomass yield. At the time of sampling, pots were washed draining out all the soil from the pot to get all the roots. To get the dry weight, plant samples were oven dried. The following characteristics were recorded:

1. Plant height at maturity (cm).
2. Fresh biomass yield (g pot^{-1}).
3. Leaf area (cm^2).
4. Relative growth rate (RGR).
5. Net assimilation rate (NAR).
6. Relative leaf growth rate (RLGR).

Relative growth rate, net assimilation rate and relative leaf growth rate were calculated according to the formulae [Radford 1967]. These formulae are expressed as follows:

$$RGR = (Log_e W_2 - Log_e W_1) / (t_2 - t_1)$$

Where W_2 and W_1 represent the total plant dry weight at times t_1 and t_2 [Rawson *et al.* 1987]. The difference between t_2 and t_1 was 10 days.

$$NAR = (W_2 - W_1) \times (Log_e A_2 - Log_e A_1)/(t_2 - t_1) \times (A_2 - A_1)$$

Where

A_1 = Initial leaf area

A_2 = Leaf area after time t_2 days

W_2 and W_1 are dry weights at t_1 and t_2, respectively.

Leaf area ratio was determined as quotient of total plant dry weight to leaf area and the composite of SLA (specific leaf area) x LWR (leaf weight ratio).

SLA = Leaf area/leaf weight

LAR = leaf area/total plant weight

After harvesting, the plant leaf area was measured by Delta T Area Meter. The components organs were dried in an oven at 70 °C ± 1 for 48 hours. After the completion of experiment, soil samples from 0-15 and 15-30 cm were taken from each pot. These were processed and were analyzed for EC_e, CO_3^{2-}, $HCO3^-$, Cl^-, Ca^{2+}, Mg^{2+}, Na^+ and SAR [U.S. Salinity Lab. Staff 1954].

RESULTS AND DISCUSSION

SOIL CHARACTERISTICS

Soil Salinity (EC_e)

Results indicated (Table 1) that designed waters affected the soil salinity (EC_e) significantly. After one-year application of designed brackish waters, it was noted that maximum soil salinity was 9.9 dS m^{-1} with treatment W9 [EC 6 dS m^{-1} and SAR 20 (m mol $L^{-1})^{1/2}$]. The soil salinity increased with salinity and SAR of applied irrigation water. The minimum EC_e was 2.34 dS m^{-1} with W0 (EC 0.9 dS m^{-1} and SAR 2.15). It is evident that EC of soil profile was 4.3, 3.9, 3.4, 3.0, 2.7, 2.4, 2.2, 1.9 and 1.5 times more with W9 followed by W8 to W1 over the control (W0). Higher the salinity and SAR of water, higher saline is the soil. The increase in

EC_e was more with EC_{iw} at higher than that at lower levels of SAR_{iw}. Increase in salinity of normal soils with EC_{iw} was reported earliar [Saleem *et al.* 1993, Abid 2000]. It is apparent that EC of soil was more than EC of water used for irrigation. The pots were closed at the bottom, the salts through each irrigation were not leached down, so there was more development in soil salinity than that of the applied EC_{iw}. Results indicated that EC_e was > 4.0 dS m^{-1} with W2 to W9 which was the upper limit for saline-sodic soils [U.S. Salinity Lab. Staff 1954, Ayres and Westcot, 1985].

Table 1: Effect of EC_{iw} and SAR_{iw} on soil salinity and SAR.

Soil salinity		Soil SAR (m mol $L^{-1})^{1/2}$	
Treatments	Original order	Treatments	Original order
W0	2.41i	W0	3.90h
W1	3.55h	W1	5.51g
W2	4.30g	W2	7.45f
W3	4.95f	W3	8.52ef
W4	5.60e	W4	9.47de
W5	6.10e	W5	9.91cde
W6	6.95d	W6	10.51cd
W7	7.93c	W7	11.27c
W8	8.99b	W8	13.06b
W9	9.90a	W9	15.94a
LSD at 5% level of significance = 0.5795		LSD at 5% level of significance = 1.391	

Mean followed by same letters are non-significant with each other at 5 % level of significance.

Soil Sodication (SAR)

Soil SAR is considered good indicator of soil sodicity. Higher SAR_{iw} at given EC_{iw} tends to increase soil sodicity, clogg pores and thereby caused decrease in water intake rate. Data in Table 1 revealed that all the treatments investigated affected the soil SAR significantly. It is evident that SAR build up was 15.9 with W9 (EC 6 dS m^{-1} and SAR 20 (m mol $L^{-1})^{1/2}$). Minimum soil SAR (1.96) was recorded with W0 [EC 0.91 dS m^{-1}; SAR 2.15 (m mol $L^{-1})^{1/2}$]. At a given EC_{iw}, the SAR_{iw} significantly increased the soil SAR. It is evident that soil SAR was 4.7, 3.9, 3.3, 3.1, 3.0, 2.8, 2.5, 2.2 and 1.6 times with W9 to W1 over the control (W0). As expected, the higher levels of Na^+, HCO_3^- and SAR_{iw} resulted in a high Na saturation in soil at a given EC_{iw}. It was observed that after one year application of brackish waters, the soil SAR value > 13.3 was recorded only with treatment W9, which is the upper limit for saline-sodic soils [Saleem *et al.* 1993, Abid 2000].

GROWTH PARAMETERS

Height and Fresh Biomass Yield

The results regarding the effect of treatments on plant height at maturity (55-days after germination) is presented in Table 2. It is evident that maximum plant height (126.18 cm) was recorded in control (W0) while minimum (82.42 cm) in the case of W9. The effect of W0 and W2 were statistical non-significant with respect to plant height. Similar was the case between W1 and W3; W5 and W6 regarding the height of plant. Results showed that the height of plant with treatment W9 was 1.5 times less than that with the W0.

Table 2: Effect of EC_{iw} and SAR_{iw} on height and fresh biomass yield of maize plant

Height (cm)		Fresh biomass yield (g pot^{-1})	
Treatments	Original order	Treatments	Original order
W0	126.18a	W0	188.78a
W1	111.15b	W1	181.69a
W2	122.38a	W2	149.68b
W3	112.44b	W3	150.84b
W4	106.08bc	W4	119.43c
W5	103.98c	W5	109.74cd
W6	99.72c	W6	106.96d
W7	85.63de	W7	75.66e
W8	86.32d	W8	62.60f
W9	82.42e	W9	47.07g
LSD at 5% level of significance = 7.021		LSD at 5% level of significance = 5.838	

Mean followed by same letters are non-significant with each other at 5 % level of significance.

Critical examination of data (Table 2) revealed that maximum fresh biomass yield was produced with W0 (188.78 g pot^{-1}), whereas minimum (47.07 g pot^{-1}) with treatment W9. The treatment W9 had resulted 4.0 times less fresh biomass yield than that of treatment W0 (i.e. control). It is interesting to note that yield resulted from control was statistically non-significant with that of treatment W1. Similar was the case between W2 and W3 on yield of maize. Results indicated that maize variety investigated in the present study could tolerate EC_{iw} and SAR_{iw} up to 2 dS m^{-1} and 10 (mmol $L^{-1})^{1/2}$, respectively. It is reported earliar that maize is a relatively sensitive to EC_{iw} showing 50 % reduction in yield with EC_{iw} 3.9 dS m^{-1} [Ayres and Westcot 1985]. Higher levels of EC_{iw} and SAR_{iw} have significantly reduced the fresh biomass yield of maize (Table 2).

Reduction in height and fodder yield of maize might be due to osmotic effect of salts in irrigation waters [Greenway and Munns 1980], antagonistic/synergistic effects of Na, Ca, Mg, CO_3, HCO_3, Cl and SO_4 ions [Staple and Toenniessen 1984] or specific ion toxicity [Ayres and Westcot 1985]. Addition of salts in each irrigation continuously keeps changing the osmotic potential of soil solution. This fluctuation in osmotic potential adversely influenced the physiological availability of water, which is largely a function of the difference between the osmotic potential of the plant root cell and the sum of the osmotic potential of the soil solution [Suarez and Lebron 1993]. As a result of which plants could not maintained turgor and thus reduced height and fodder yield [Arif 1990].

PHYSIOLOGICAL GROWTH PARAMETERS

Relative Growth Rate (RGR)

Results (Table 3) divulged that relative growth rate (RGR) remained fluctuating from first harvest to the last harvest. All the nine treatments (W1 to W9) depressed the RGR in all the three harvests. Maximum RGR was produced with W0 while minimum in the case of W9. It is evident that

Table 3: Effect of EC_{iw} and SAR_{iw} on physiological growth parameters of maize variety Sultan.

Treatments	Relative growth rate (RGR) (mg g^{-1} day^{-1})			Net assimilation rate (NAR) (mg cm^2 day^{-1})			Relative leaf growth rate (RLGR) (mg g^{-1} day^{-1})		
	Harvest 1	Harvest 2	Harvest 3	Harvest 1	Harvest 2	Harvest 3	Harvest 1	Harvest 2	Harvest 3
W0	0.145a	0.137a	0.061bc	0.813a	0.783a	0.320ab	1.152a	0.858b	0.834a
W1	0.109abc	0.097cde	0.085a	0.478c	0.337cd	0.287ab	0.771abc	0.728bc	0.362b
W2	0.098abc	0.039ef	0.059b	0.455c	0.240de	0.184bcd	0.732bcd	1.371a	0.353b
W3	0.128ab	0.037ef	0.054bc	0.455c	0.231de	0.105cd	0.428cd	0.656bc	0.337b
W4	0.114abc	0.078bc	0.041c	0.703ab	0.508b	0.337a	0.863ab	0.560cd	0.298b
W5	0.068c	0.070bcd	0.026c	0.744a	0.400bc	0.262abc	0.713bcd	0.533cd	0.256b
W6	0.067c	0.066bcd	0.023c	0.263b	0.412bc	0.189abcd	0.585bcd	0.409b	0.253b
W7	0.089bc	0.093b	0.038c	0.473bc	0.441bc	0.208abcd	0.769ab	0.528cd	0.356b
W8	0.146a	0.046de	0.022c	0.545cd	0.336cd	0.193abcd	0.350d	0.150e	0.285b
W9	0.064c	0.018f	0.023c	0.405cd	0.107e	0.102d	0.396cd	0.142e	0.236b
LSD at 5 % levels of significance		0.0226	0.0463	0.1843	0.1361	0.1588	0.3979	0.2385	0.2628

Mean followed by same letters in columns are non-significant at 5 % level of significance.

RGR decreased with increasing EC_{iw} and SAR_{iw} and with age of the plant (Table 3). It indicated that maize variety Sultan under investigation was tolerant at the beginning while became sensitive to EC and SAR of waters towards the latter growth stages. In a pot experiment at Directorate of Soil Salinity at Pindi Bhattian, Mahmood *et al.* [1991] reported that RGR decreased with soil salinity during the flowering growth stage of rice variety IRR6. The decrease in RGR with W1 to W9 might be due to accumulation of solutes in the rhizosphere. Moreover, at last harvest W5 to W9 behaved statistically non-significant with each other in this growth parameter (Table 3). Rozena and Visser [1991] and Pitman [1972] have accentuated the use of mean RGR as salt tolerance index of various plant species.

Net Assimilation Rate (NAR)

A close observation of Table 3 shows that NAR (rate of biomass assimilation) decreased with treatments investigated and also with growth stages. At harvest I, the maximum NAR (0.81 g cm^{-2} day^{-1}) was noted in control. It decreased with salinity and SAR of applied waters. However, W6 has resulted the lowest (0.26 g cm^{-2} day^{-1}) NAR in the present investigations.

The NAR increased at harvest I with an increase in the relative growth rate (RGR). The effect of treatments was more pronounced on NAR at harvest II and III. This was attributed mainly due to decrease in relative growth rate. At given SAR_{iw}, the decrease in NAR was more with an increase in salinity of water. Like relative growth rate, decrease in NAR might be due to accumulation of solutes in the root medium, which reduces the physiological availability of water to the plant. As the growth progressed from first to the last harvest, generally, the value of NAR (rate of biomass assimilation) first increased and then decreased in control and also with the treatments investigated. It is evident from the data that the increase of NAR causes the increase of RGR and vice versa which showed the positive correlation between NAR and RGR. Shanon [1997] reported that net assimilation rate of sunflower decreased with higher levels of NaCl salinity in the soil.

Relative Leaf Growth Rate (RLGR)

The physiological efficiency of maize plant expressed in terms of relative leaf growth rate (RLGR) revealed a declining trend with designed brackish waters. The RLGR decreased gradually in the control from first harvest to the last harvest. Results indicated that there was a minor decrease in relative leaf growth rate with an increase in the water salinity at later growth stages (harvest III). It is evident from data (Table 3) that at given EC_{iw}, the RLGR increased with SAR_{iw}. Minimum RLGR was noted with W9 and maximum in the case of W0. Like relative growth rate, net assimilation rate, the relative leaf growth rate increase in the first and gradually decreased in the latter growth stages. The effect of all the nine treatments on RLGR was more pronounced in the last harvest. More declining in this parameter at latter stages of growth appeared as a result of greater sensitivity of maize to ionic stress. Ashraf and O'Leary [1995] reported the similar mechanism for sunflower grown under saline conditions.

CONCLUSIONS

Following conclusions were drawn from the present study:

1. The soil salinity increased with brackish water irrigations. The EC_e was 4.3, 3.9, 3.4, 2.7, 2.4, 2.2, 1.9 and 1.5 times more with W9 [EC_{iw} 6 dS m^{-1} and SAR (20 m mol $L^{-1})^{1/2}$] followed by W8 to W1 over control (W0).
2. Soil SAR increased with designed brackish water irrigation. The soil SAR value > 13.3 were noted with W9, which is the upper limit for saline-sodic soils.
3. The EC_{iw} 2 dS m^{-1} and SAR_{iw} 10 (m mol $L^{-1})^{1/2}$ was considered the best water regarding the height and biomass yield of the designed maize variety.
4. The physiological growth parameters such as RGR, NAR and RLGR changed with designed waters, however, the effect of EC_{iw} and SAR_{iw} was more pronounced at higher levels than that at lower levels.

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