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Physiological and morphological traits of Maize hybrids under saline water irrigation

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Salinity is one of the common abiotic stresses affecting crop growth and yield considerably. Hence, we conducted a pot culture experiment to evaluate the changes in various physiological and morphological traits of six maize hybrids (CO 6, CO 7, CO 8, CO 10, NK 6240 and 900 M Gold) under saline water irrigation. Saline water having a natural EC of 0.6, 3.2, 4.8, 6.7 and 8.9 dSm^{-1} was used for irrigating the crops up to 30 days. Nine seedling traits *viz*., shoot length, root length, shoot dry weight, root dry weight, total dry weight, photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll content were measured. Based on the better physiological and morphological traits, dry matter productivity (DMP) and gas exchange parameters, the maize hybrids CO 6 and CO 7 have been identified as saline water tolerant up to an ECiw of 4.8 dSm^{-1}. However, CO 8 was observed as salt sensitive as it recorded poor growth and photosynthetic parameters. Results suggest that DMP and gas exchange parameters would be useful traits for identifying salinity tolerance in maize hybrids at seedling stage.

Keywords: Abiotic stress, DMP, Gas exchange parameters, Growth attributes, Osmotic stress, Soil salinity, Tolerance, *Zea mays* L.

Depleting resources and increasing demand for freshwater has lead to water scarcity worldwide. Agriculture sector is one of the major consumers of freshwater for higher crop yields, and water availability plays a major role in sustaining the crop growth. In this context, poor quality water has been considered as an alternative source for agriculture. However, proper management strategies need to be followed to avoid yield loss and soil health deterioration[1].

Soil salinity is one of the major environmental abiotic stresses that limits the agricultural productivity and food supply worldwide. The total global area under salt affected soils account for 830 million hectares, of which about 20% salt affected soil was developed due to poor quality water irrigation[2]. Burgeoning population particularly in developing and under developed countries of the world coupled with concomitant decline in area under agriculture, necessitated to tackle these soil stresses urgently[3]. Salinity affects plants in different ways by changing osmotic potentials, creating ion toxicities, nutritional disorders and imbalances, etc. It makes soil highly unproductive and hence yield loss is inevitable[4,5]. These deteriorative factors not only changes the plant morphology, but also modifies the plant metabolic activities, thus limiting their vegetative and reproductive growth, which has profound implications on crop yield[6,7].

Salinisation of water and soil led the plant scientists to develop salt-tolerant crops through various genetic and physiological approaches to achieve sustainable yield in many crops[8-10]. Maize (*Zea mays* L.) is one of the moderately salt-sensitive field crop, showing obvious signs of stress, including wilting, dull leaves, and gray leaf tips even when there is adequate soil moisture. Maize grown under salinity though showed reduction in growth and yield and wider genetic variability exist among genotypes for salt tolerance like other plant species *viz*., rice, sunflower and vegetables[11-14]. Further, salinity tolerance differs with crop growth stages, hence better physiological and morphological characters were considered as positive traits for identification of tolerant genotypes. The ability of the plants to sustain the irrigation water salinity depends on many plant traits, such as K^+/Na^+ ratio, K^+ content, biomass production, gas exchange parameters, etc.[15-18]. Keeping this in view, we conducted a pot culture

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experiment to screen various maize hybrids under different levels of natural irrigation water salinity (EC_{iw}) for their tolerance and sensitiveness.

Materials and Methods

Plant material and growing conditions

A pot experiment was conducted with six maize hybrids with five irrigation water salinity (EC_{iw}) levels on a clay loam soil. Six maize hybrids *viz*., CO 6, CO 7, CO 8, CO 10, NK 6240 and 900 M Gold were chosen and assessed for their response to irrigation water salinity. One kilogram of processed soil was filled in the plastic pots having two kilogram capacity and the maize hybrids were dibbled at one seed/pot.

Treatments

Based on the similarity in chemical composition, five water samples naturally differing in their electrical conductivity (EC_{iw}: 0.6, 3.2, 4.8, 6.7 and 8.9 dSm^{-1}) was selected for conducting the experiment. Selected maize hybrids were sown in the pots and one plant per pot was maintained for 30 days. The crop was continuously irrigated with saline water having various ECiw levels at 250 mL/pot/irrigation at an interval of once in 3-4 days. Nutrients in the form of Urea, Super phosphate and Muriate of Potash were applied basally as per fertilizer recommendation (250:75:75 kg NPK ha^{-1}) and the crop was grown up to 30 days and harvested.

Growth measurement

Morphological parameters, such as plant height, root length, lateral root length and dry matter production (DMP) of the crop on 30 DAS were measured. The plant samples were dried at 70°C for 72 h in a hot air oven and the plant dry weight was recorded. Measurements of physiological parameters, such as photosynthetic rate, stomatal conductance and transpiration rate were measured between 8:00 and 10:00 a.m. after 30 days of salt stress on the first fully expanded leaf using a portable photosynthesis system, infra-red gas analyser (LI-6800). Relative chlorophyll content (SPAD index) was also determined on the first fully expanded leaf, by registering three readings per leaf with a portable Minolta chlorophyll meter SPAD-502. Based on the biomass production (DMP), the stress tolerance index was calculated for different levels of irrigation water salinity to understand the tolerance and sensitiveness of the maize hybrids.

Statistical analysis

Growth parameters have been presented as mean ±SD of three replicates. It was statistically analyzed by applying ANOVA with interaction followed by factorial completely randomized design (CRD). The standard error bars for each treatment was also computed and furnished.

Results

Plant morphological parameters

Saline water irrigation significantly reduced the growth attributes of all the maize hybrids and the extent of reduction varied with their genotypic difference. Increasing levels of salinity decreased the plant height, root length and lateral root length of all the maize hybrids (Tables 1 & 2) and the mean values varied between 61.2 to 46.9 cm, 22.7 to 18.6 cm and 5.74 to 4.40 cm, respectively. Higher growth attributes in all the maize hybrids were observed with

Table 1 — Effect of saline water irrigation on plant height and root length of maize hybrids

M	Plant Height (cm)						Root Length (cm)					
EC levels (dSm^{-1})	0.6	3.2	4.8	6.7	8.9	Mean	0.6	3.2	4.8	6.7	8.9	Mean
CO 6	69.2±1.52	67.5±1.80	63.0±1.71	58.7±1.14	47.6±1.20	61.2	29.8±0.81	25.5±1.17	22.7±0.82	19.8±0.49	15.5±0.59	22.7
CO 7	64.0±1.81	62.5±1.91	57.8±2.15	52.3±2.16	46.9±0.95	56.7	28.7±0.74	25.0±0.94	21.9±0.94	19.4±0.56	15.2±0.75	22.1
CO 8	60.2±2.12	55.5±1.43	49.5±1.54	39.4±1.41	30.2±0.74	46.9	26.0±0.63	22.5±0.73	18.5±0.74	14.7±0.55	11.2±0.68	18.6
CO 10	61.7±1.93	58.9±0.84	47.2±1.10	40.5±1.27	35.2±1.17	48.7	26.6±0.71	23.8±0.87	19.9±0.86	16.6±0.49	11.3±0.48	19.6
NK 6240	63.5±1.87	57.0±1.52	53.6±1.37	50.2±1.35	41.2±0.92	53.1	28.5±0.92	24.6±1.25	21.1±0.94	18.2±0.53	14.3±0.55	21.3
900 M Gold	63.7±1.63	58.5±1.41	50.7±1.29	42.1±1.41	39.8±0.86	51.0	27.3±0.84	24.1±1.12	20.6±0.97	16.9±0.67	12.3±0.57	20.3
Mean	63.7	60.0	53.6	47.2	40.2	52.9	27.8	24.3	20.8	17.6	13.3	20.8
	EC	M	ECxM				EC	M	ECxM			
SEd	0.48	0.52	1.18				0.21	0.24	0.53			
CD (P=0.05)	0.96	1.05	2.35				0.43	0.48	1.07			

[EC, Electrical conductivity; M, Maize hybrids]

Table 2 — Effect of saline water irrigation on lateral root length and root weight of maize hybrids

M EC levels (dSm^{-1})	Lateral root length (cm)						Root weight (g)					
	0.6	3.2	4.8	6.7	8.9	Mean	0.6	3.2	4.8	6.7	8.9	Mean
CO 6	7.17±0.41	6.33±0.39	5.90±0.53	5.07±0.42	4.23±0.32	5.74	2.15±0.39	1.93±0.47	1.86±0.36	1.72±0.44	1.54±0.43	1.84
CO 7	6.77±0.42	6.27±0.47	5.20±0.42	4.67±0.28	3.97±0.28	5.37	2.02±0.58	1.87±0.44	1.71±0.48	1.55±0.52	1.35±0.38	1.70
CO 8	6.00±0.38	5.10±0.54	4.40±0.47	3.70±0.39	2.80±0.21	4.40	1.94±0.47	1.71±0.42	1.58±0.57	1.34±0.58	0.94±0.25	1.50
CO 10	6.60±0.40	5.73±0.42	4.93±0.56	3.63±0.45	3.00±0.19	4.78	1.99±0.47	1.84±0.38	1.62±0.55	1.39±0.67	1.08±0.29	1.58
NK 6240	6.47±0.52	5.60±0.49	5.10±0.58	4.50±0.29	3.70±0.21	5.07	2.07±0.39	1.93±0.41	1.75±0.37	1.59±0.51	1.20±0.41	1.71
900 M Gold	6.23±0.48	5.43±0.52	4.90±0.47	3.73±0.38	3.13±0.22	4.69	2.01±0.54	1.87±0.57	1.62±0.46	1.48±0.52	1.22±0.38	1.64
Mean	6.54	5.74	5.07	4.22	3.47	5.01	2.03	1.86	1.69	1.51	1.22	1.66
	EC	M	ECxM				EC	M	ECxM			
SEd	0.04	0.05	0.12				0.01	0.01	0.03			
CD (P=0.05)	0.09	0.10	1.24				0.03	0.03	0.07			

[EC, Electrical conductivity; M, Maize hybrids]

Table 3 — Effect of saline water irrigation on the shoot and total dry matter production of maize hybrids

M EC levels (dSm^{-1})	Shoot weight (g)						Total DMP (g)					
	0.6	3.2	4.8	6.7	8.9	Mean	0.6	3.2	4.8	6.7	8.9	Mean
CO 6	4.02±1.07	3.91±0.87	3.58±0.59	2.82±0.76	1.83±0.97	3.23	6.50±1.12	6.23±1.07	5.66±0.85	4.75±0.97	3.84±0.57	5.40
CO 7	3.67±0.89	3.44±0.74	3.28±0.78	2.60±0.71	1.61±0.88	2.92	6.12±1.02	5.67±1.07	5.20±0.76	4.23±0.91	3.36±0.74	4.92
CO 8	3.49±0.78	2.71±0.67	1.69±0.88	0.96±0.84	0.95±0.48	1.96	5.40±1.08	4.76±0.78	3.80±0.69	2.68±0.87	1.99±0.52	3.73
CO 10	3.31±0.76	2.73±0.87	1.88±0.76	1.38±0.89	1.02±0.59	2.07	5.50±1.01	4.95±0.89	4.11±0.73	2.97±0.92	2.19±0.49	3.95
NK 6240	3.52±0.87	3.10±0.73	2.48±0.68	1.85±0.94	1.26±0.72	2.44	5.93±1.11	5.47±0.99	4.89±0.87	3.69±0.82	3.02±0.47	4.60
900 M Gold	3.44±0.99	2.80±0.63	1.71±0.82	1.36±0.76	1.09±0.66	2.08	5.74±1.07	5.10±0.87	4.43±0.91	3.39±0.78	2.61±0.49	4.25
Mean	3.58	3.11	2.44	1.83	1.29	2.45	5.87	5.36	4.68	3.62	2.84	4.47
	EC	M	ECxM				EC	M	ECxM			
SEd	0.06	0.07	0.15				0.06	0.06	0.14			
CD (P=0.05)	0.12	0.14	0.30				0.12	0.13	0.29			

[EC, Electrical conductivity; M, Maize hybrids]

non saline water (0.6 dSm^{-1}) irrigation while greater reduction in all the attributes was observed in pots receiving an irrigation water salinity of 8.9 dSm^{-1}.

Decrease in plant growth attributes due to various levels of irrigation water salinity was lesser in the genotypes CO 6, CO 7 and NK 6240. The highest mean plant height of 61.2 cm was recorded in CO 6 which was followed by CO 7 (56.7 cm) and NK 6240 (53.1 cm). However, it can tolerate the EC_{iw} up to 4.8 dSm^{-1} only and beyond that level higher reduction in plant height was observed. The lowest mean plant height was registered with CO 8 (46.9 cm) and CO 10 (48.7 cm). Considerable increase in plant height of other maize hybrids (NK 6240, CO 10, 900 M gold and CO 8) was observed up to an EC_{iw} of 3.2 dSm^{-1} only and above that level all the growth attributes were reduced markedly.

Growing crops under different EC_{iw} have shown wider differences in root length and lateral root length of the crops as that of plant height. The highest mean root length (22.7 cm) and lateral root length (5.74 cm) was recorded in CO 6 which was followed by CO 7 (22.1 and 5.37 cm). The lowest root length and lateral root length was registered with CO 8 (18.6 and 4.40 cm) and CO 10 (19.6 and 4.78 cm). The lateral root length of the crops also affected by various EC_{iw} levels considerably (6.54 to 3.47 cm) and more than 50 per cent reduction was noticed with an EC_{iw} of 8.9 dSm^{-1} (3.47 cm) over non saline water (6.54 cm).

Dry matter productivity (DMP)

Salinity stress significantly reduced the plant growth attributes hence results in greater reduction in plant biomass production. There was a marked decrease in shoot and root dry weights of all the maize hybrids due to the deterrent effect of salinity on plant growth. The shoot and root biomass production by different maize hybrids was reduced from 6.50 to 1.99 g with increasing irrigation water salinity (Tables 2 & 3). The highest mean DMP was obtained with CO 6 (5.40 g/plant) and CO 7 (4.92 g/plant) with a per cent reduction of 21.2 to 24.96%, respectively. However, CO 8 was found highly sensitive by recording lesser DMP (3.73 g/plant). The mean reduction rate in total plant DMP of genotypes at different EC_{iw} levels was maximum with CO 8 (38.7 %) and lesser reduction in CO 6 (21.2 %) regardless of water salinity.

Shoot dry weight of maize hybrid was negatively affected by increasing EC_{iw} levels. Based on the rate of reduction in shoot dry weight from highest to lowest value the genotypes were arranged as: CO 6 > CO7 > NK6240 > 900 M Gold > CO10 > CO8 and the mean shoot dry weights were 3.23 > 2.92 > 2.44 > 2.08 > 2.07 > 1.96 g/plant, respectively. The maximum reduction in shoot dry weight was observed in CO 8 (1.96 g/plant) and minimum in CO6 (3.23 g/plant) and CO 7 (2.92 g/plant). The reduction in shoot DMP was varied from 2.74 to 72.8%.

Root DMP of hybrids also decreased significantly as the levels of EC_{iw} increased from 0.6 to 8.9 dSm^{-1} (Table 2). The highest root DMP was registered by the plants irrigated with non saline water (0.6 dSm^{-1}) while the lowest root DMP was noticed in the plants irrigated with the water salinity of 8.9 dSm^{-1}. The hybrids, CO 6 (1.84 g/plant) and CO 7 (1.70 g/plant) were not affected considerably by saline water irrigation up to 4.8 dSm^{-1} and CO 8 registered the highest reduction in root DMP (1.50 g/plant) even at lesser water salinity.

Physiological parameters

Plant physiological parameters, such as photosynthesis, stomatal conductance, transpiration and chlorophyll content were greatly decreased with increase in irrigation water salinity at 30 days (Fig. 1). Photosynthetic rate of the maize hybrids (Fig. 1A) ranged from 32.8 to 17.9 µmol m^{-2} s^{-1} and the highest mean value was recorded in CO 6 (27.1 µmol m^{-2} s^{-1}) followed by CO 7 (26.0 µmol m^{-2} s^{-1}). The lesser photosynthetic rate was observed in CO 8 (23.1 µmol m^{-2} s^{-1}). Similar trend of results was observed in stomatal conductance (Fig 1B), transpiration rate (Fig 1C) and chlorophyll content (Fig. 2) and the values varied from 0.68 to 0.12 mol m^{-2} s^{-1}, 7.35 to 2.05 mmol m^{-2} s^{-1} and 43.8 to 30.3 (SPAD Index), respectively. Highest mean values of all these parameters were observed in the maize hybrids CO 6 and CO 7 and the lowest values were recorded with CO 8.

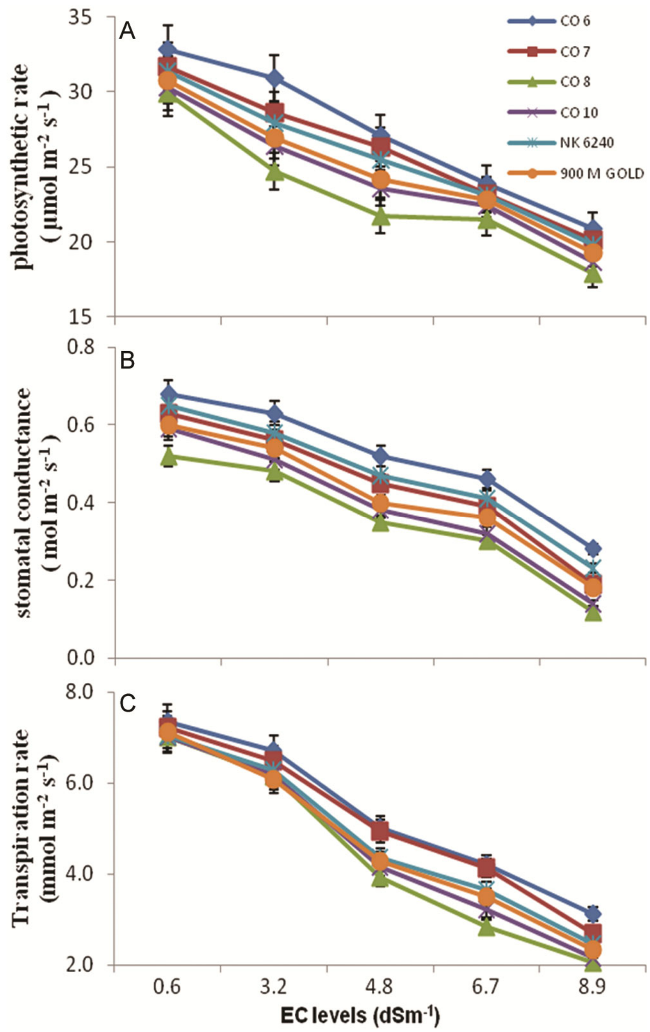

Fig. 1 — Photosynthetic activity of maize hybrids (A) Photosynthetic rate; (B) Stomatal conductance; and (C) Transpiration

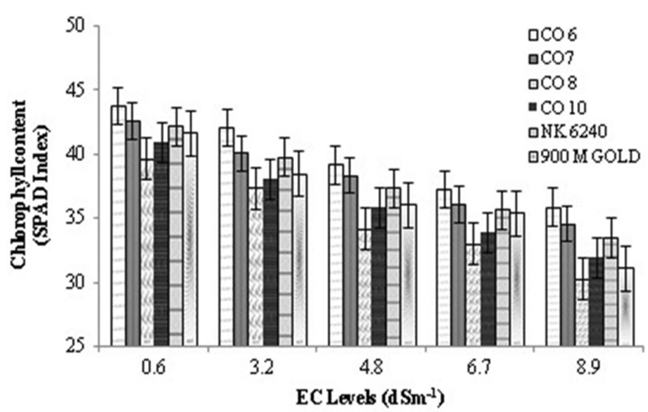

Fig. 2 — Effect of saline water irrigation on chlorophyll content (SPAD index) of maize hybrids

Discussion

Salinity reduced the growth and biomass production of maize hybrids and this study reveals the existence of genotypic variation among the maize hybrids for their tolerance to irrigation water salinity. The maize hybrids CO 6 and CO 7 were found to tolerate the irrigation water salinity up to 4.8 dSm^{-1} while the genotypes CO 8 and CO 10 suffered with greater growth reduction even at lesser water salinity suggesting that these genotypes were the most salt sensitive. Salinity results in significant decrease in shoot length, root length and leaf area of maize and the reduction may be due to decreased osmotic potential and ion toxicity[19,20]. Plant root is an organ which supplies all essential nutrients from the growth medium to growing regions of plant. Hence, root response provides useful information for salinity tolerance of plants. In our study, root length and dry weights were significantly reduced under salinity and the maximum root length was noticed in CO 6 and the minimum was recorded in CO 8. Similar findings were observed in maize and reported that salinity inhibited shoot and root length of maize plants considerably[17].

Irrigation water salinity inhibited the growth of maize hybrids significantly and led to a decrease in dry biomass production. This may be related to the effect of salt stress which resulted in the limitation of water absorption and biochemical processes[21]. Shoot dry weights of all the tested maize genotypes were decreased significantly at 8.9 $dSm^{-1}$of EC_{iw} (Table 2). Reduction was more in CO 8 as compared to CO 6. The suppression of plant growth under salt-stress may either be due to osmotic reduction in water availability or due to excessive accumulation of ions, known as specific ion effect. There are many reports on osmotic stress and ionic toxicity resulted from salt stress in maize plants. Our results are in accordance with the findings reported by them *i.e.* dry weight of the maize hybrids was decreased with increasing water salinity[22,23].

Salinity stress has been shown to reduce the overall growth and productivity of plants by disturbing several physiological and biochemical processes like photosynthesis, ion homeostasis and enzyme activities[24,25]. Our results are in agreement with those previously reported in different crops such as cowpea, cotton, sorghum, maize and pea[26].

Physiological parameters and chlorophyll content in the maize hybrid was as: CO 6 > CO 7 > NK 6240 > 900 M Gold > CO 10 > CO 8. It has been reported that reduction in photosynthesis by lesser stomatal conductance, which causes CO_2 availability, during early exposure to salt stress, while biochemical limitations arises due to long-term salt exposure[27,28].

Measurement of stomatal conductance provides effectual comparison for determining the degree of stress in plants. Salinity decreased the stomatal conductance in maize hybrids, which could be explained by inhibition of plant growth due to water stress. A strong positive correlation between stomatal conductance and irrigation water salinity was observed in this study confirms that stomatal factors have more significant effect on photosynthesis[29].

The chlorophyll content in the maize leaves was also reduced by increasing levels of irrigation water salinity. Salinity decreased the chlorophyll concentration of maize varieties and the reduction in photon yield in the salt stressed seedlings of maize was positively correlated with net photosynthetic rate[18]. Many scientists have suggested a positive correlation between decrease in chlorophyll content and salt-induced weakening of protein-pigment-lipid complex[30,31]. Thus, the reduction in photosynthesis in maize plants was caused by stomatal closure, decreasing transpiration rate and intercellular CO_2 concentration for Rubisco activity[32,33].

Conclusion

The present study has demonstrated that evaluation of maize hybrids at early growth stages is the simple and quick method for determining genotypic and physiological differences in response to irrigation water salinity. The present study showed that irrigation water salinity considerably reduced the plant growth and biomass production of all the maize hybrids and differs widely. The physiological parameters, such as photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll content of the plants were also decreased with increasing salinity. It was identified that the maize hybrids CO 6 and CO 7 were tolerant to saline water irrigation up to an ECiw of 4.8 dSm^{-1} by recording better morphological and physiological attributes and DMP. The hybrid CO 8 was found highly salt sensitive as it showed reduced growth and poor photosynthetic mechanisms even at lesser irrigation water salinity (0.60 dSm^{-1}) but tolerated up to an ECiw of 3.20 dSm^{-1}.

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