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Phyto-reclamation potentials of crops grown in calcareous saline: Sodic soils

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Abstract
Saline sodic soils are steadily expanding worldwide due to climatic changes and water shortage especially in arid and semi-arid regions. It is characterized by the occurrence of salt and sodium (Na^+) levels that can adversely affect several soil properties and growth of the crops. Hence assessing the phytoreclamation potentials of salt tolerant crops forms an alternate component in the many low cost technologies for the costly chemical reclamation approaches. A greenhouse screening experiment was conducted with various agricultural crops to investigates the ameliorative effect of crops in calcareous saline-sodic soils having varied intensity of saline-sodicity. Eighteen crops viz, *Oryza sativa* (TRY3), *Zea mays* (CO6), *Eleusine coracana* (CO15), *Helianthus annuus* (CO4), *Gossypium hirsutum* (MCU13) *Amaranthus cruentus* (CO1), *Medicago sativa* (CO2), *Sesbania bispinosa* (culture), *Pennisetum glaucum* (CO9), *Sorghum bicolor* (CO3), *Panicum sumatrense* (CO1), *Paspalum scrobiculatum* (CO3), *Panicum miliaceum* (CO5), *Setaria italic*a (CO7), *Echinochloa frumentacea* (CO2), *Sesamum indicum* (CO1), Fodder *Zea mays* (African tall), Fodder S*orghum bicolor* (CO29) were grown in soils having varied levels of natural soil salinity (EC =< 2, 2-4, 4-6, 6-8 and 8-16 dSm^{-1}). Differential response of crops for saline-sodicity was observed and generally plant growth and biomass production decreased with increasing saline-sodicity. The tissues concentration of Na^+ and Cl^- ions were increasing with increasing saline-sodicity in contrary to the K^+ and Ca^{2+} absorption which decline with increasing saline-sodicity. Better growth performance, higher Na+ and salt removal potentials of the crops *Zea mays* and *Eleusine coracana* indicated their suitability for phytoreclamation of calcareous saline-sodic soils. However the small millets *Panicum miliaceum* and *Setaria italica* were highly susceptible to saline-sodicity.

Keywords: Salt stress, crops, growth, tissue concentration of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-

Introduction
Soil salinity, is one of the major abiotic stress limiting the productivity of many agricultural crops and considerably degrading the arid and semi-arid lands areas of the world. About 831 x 10^6 hectares of land is affected by salinity which accounts for faulty irrigation practices, regular use of saline water, lesser rainfall, salinisation of underground water, etc. Salinity limits the productivity in 6 % of land and 15 % of the total cultivable area in the world (Bhantana and Lazarovitch, 2010; Siringam *et al.*, 2012; Shahid *et al.*, 2012) [4, 17, 16]. Though many factors are detrimental to crop productivity in these soils, presence of higher concentration of Na^+ and Cl^- ions further aggravated the crop growth and nutritional issues by disturbing physiological and biochemical metabolisms in plants (Grieve *et al.*, 2007) [9]. Salinity mainly leads to imbalances in plant nutrient intake, reduces the photosynthetic rates, osmotic regulation, water use efficiency and increased toxicity due to specific ions like Na^+ and Cl^- (Ashraf and Foolad, 2007; Grewal, 2010; Cambrolle *et al.*, 2011) [2, 5]. Amelioration of these soils by chemical ameliorants is a proven technology but their increased by cost and recurrent issues necessitated the identification of suitable alternate technologies. Hence reclaiming these soils requires efficient, low cost amelioration strategies besides better management strategies. In this context, assessing the potentials of salt tolerance and removal efficiency plays a vital role in reducing cost of reclamation.

Crops vary significantly to salt stress and identifying a genotype with better salt tolerance helps to sustain the effect of various approaches used to improve the productivity of crops in saline- sodic soils. Many scientific researches has demonstrated that salt affected soils can be effectively ameliorated using plants through phyto-remediation approach which is achieved by the removal of Na^+ and Cl^- ions in plant biomass and also by the dissolution of ative calcite by root action. Salt tolerance of crops through various strategies like morphological, physiological, biochemical and enzymatic responses to salt stress was reported in various field crops (Shahid *et al.*, 2012; Salih Aydemir and Halime Sunger, 2012; Somaye Sardouie Nasab *et al*, 2015) [16, 13, 15]. However the tolerance mechanism varies widely with location due to wide variability in climate, soil physico chemical properties, rainfall, etc which reduces their efficiency under field conditions. Further, most of the studies were conducted in simulated salt stress situations under solution or sand culture experiments. Hence screening the crops for their Phyto-reclamation potentials under natural soil saline - sodicity needs to be attempted to know the extent of variability exists among the crops for their tolerance to salt stress. Hence the current study was proposed (1) to assess the phyto-reclamation potential of various agricultural crops grown under calcareous saline-sodic soil (2) and to identify the plants having better biomass production and salt removal efficiency.

Materials and Methods

A green house experiment was conducted with eighteen agricultural crops in four different calcareous saline-sodic soils having varied salinity to assess their crop growth response, salt removal potentials and calcite dissolution potentials for 30 days. Surface soil samples (0-15 cm) of various calcareous saline- sodic soils in bulk were collected from many farmers fields at Trichy, Ramanathapuram, Coimbatore districts of Tamil Nadu. The soils were air dried, passed through 2 mm sieve, thoroughly mixed and analysed for selected soil properties as per standard procedure (Table1). Polyethylene pots of two kilogram capacity was chosen and filled with one kilogram of processed calcareous saline - sodic soils having four levels of natural salinity (EC 2-4 (SS1), 4-6 (SS2), 6-8 (SS3) and 8-16 (SS4) dSm^{-1}) in comparison with the non- saline sodic sol. Eighteen crop varieties such as *Oryza sativa* (TRY3)**,** *Zea mays* (CO6**)**, *Eleusine coracana* (CO15), *Helianthus annuus* (CO4)**,** *Gossypium hirsutum* (MCU13) *Amaranths cruentus* (CO1), *Medicago sativa* (CO2), *Sesbania bispinosa* (culture), *Pennisetum glaucum* (CO9), *Sorghum bicolor* (CO3)**,** *Panicum sumatrense* (CO1), *Paspalum scrobiculatum* (CO3), *Panicum miliaceum* (CO5), *Setaria italic*a (CO7) *Echinochloa frumentacea* (CO2), *Sesamum indicum* (CO1), Fodder *Zea mays* (African tall) Fodder S*orghum bicolor* (CO29) were chosen for the study. Two seeds of each crop were sown per pot and irrigated with normal water. Soil water content was maintained at field capacity on weight basis. Recommended fertilizers nutrients for each crop was applied basally and the crops were grown upto 30 days and harvested. Harvested plant samples were washed thoroughly with distilled water and dilute HCl to remove the adhering soil particles and other contaminants, air dried and oven dried at 65 ^{0}C for two days to estimate the dry matter production. The oven dried plant samples were powdered in a Willey mill and one gram of powdered plant samples were wet acid digested and analysed for K^+ and Na^+ by flamephotometry, Ca^{2+} and Mg^{2+} by Versanate titration method and Cl^- concentration by $AgNO_3$ titration method (Piper, 1946; Chapman and Pratt, 1982). After harvest of the crops, composite soil samples were collected, air and sieved to pass through 2mm sieve. Soil EC_e and pH_e were determined in saturation paste extract and 1: 2.5 soil water ratio respectively (Jackson, 1973). The free CaCO3 was measured by titration method (Piper, 1944) and per cent dissolution was computed. Plant growth response in different saline - sodic soils were recorded and the data was analyzed with factorial complete randomized designs with three replicates at p = 0.05.

Table 1: Selected physico chemical properties of the calcareous saline- sodic soils

Parameters	Saline -Sodic soils				
	NSS	SS1	SS2	SS3	SS4
pH_e	7.60	8.20	8.20	8.20	8.30
EC_e (dSm^{-1})	1.42	2.32	4.50	6.30	12.3
Free $CaCO_3$ (g kg^{-1})	38.0	101	133	112	155
Na (Meq 100g $soil^{-1}$)	4.60	8.42	13.5	16.0	17.8
K (Meq 100g $soil^{-1}$)	2.30	1.33	1.72	1.89	1.75
Ca (Meq 100g $soil^{-1}$)	17.5	15.5	18.9	16.9	14.6
Mg (Meq 100g $soil^{-1}$)	8.20	5.85	5.25	7.20	8.50
Cl^- (Meq 100g $soil^{-1}$)	28.5	30.2	35.4	42.5	75.4
CO_3^{-2}(Meq 100g $soil^{-1}$)	0.07	0.11	0.35	0.37	0.46
HCO_3^- (Meq 100g $soil^{-1}$)	0.16	0.43	0.85	0.82	0.77
ESP (%)	14.1	27.1	34.3	38.1	41.7
Textural class	Sandy loam	Sandy clay loam	Sandy clay loam	Clay loam	Clay loam

Results

Growth attributes

Salt stress significantly reduced the plant growth parameters of all the crops and the data was presented in Table 2. Statistical analysis showed that, increasing levels of saline - sodicity reduced the plant growth parameters of all the crops and the percentage reduction varied from 5.78 to 44. The crops are *Zea mays*, *Fodder Zea Mays*, *Eleusine coracana* and *Helianthus annus* recorded higher plant height in normal as well as in various calcareous saline - sodic soils. Though increasing saline - sodicity decreased the plant height in all the crops, the magnitude of reduction was lesser in these crops. The crops such as *Panicum sumatrense, Staria italica* and *Sesamum indicum* was severely affected by increasing saline-sodicity which was reflected on the lesser plant height registered at all the saline sodic soils. Rest of the crops showed moderate reduction in plant height. The growth of all the crops were higher in non- saline sodic soil than in calcareous saline -sodic soils and about 44.4 per cent reduction in plant growth was noted at higher EC (8-16 dSm^{-1}).

Table 2: Effect of native saline-sodicity on plant growth parameters

	Plant height (cm)						Root length (cm)					
	NSS	**SS1**	**SS2**	**SS3**	**SS4**	**Mean**	**NSS**	**SS1**	**SS2**	**SS3**	**SS4**	**Mean**
Oryza sativa	24.9	22.3	18.8	14.3	11.3	18.3	14.3	12.5	11.5	10.5	8.90	11.5
Zea mays	55.3	52.1	49.0	42.4	34.7	46.7	13.6	12.6	11.7	9.30	7.40	10.9
Eleusine coracana	34.8	32.3	28.3	23.6	19.9	27.8	12.8	11.8	10.3	9.70	8.43	10.6
Helianthus annuus	33.4	30.3	26.2	22.6	18.7	26.2	8.70	7.51	6.57	6.13	5.77	6.94
Gossypium hirsutum	28.4	25.7	23.8	21.0	17.1	23.2	7.97	7.50	6.57	5.93	4.50	6.49
Amaranthus cruenthus	21.1	17.6	15.7	13.7	12.3	16.1	6.77	7.30	5.57	4.67	5.47	5.95
Sesbania bispinosa	28.0	25.8	23.2	19.8	15.7	22.5	7.57	6.90	6.37	5.90	5.00	6.35
Medicago sativa	25.7	21.3	19.7	17.5	15.2	19.9	7.50	6.90	6.43	5.90	4.57	6.26
Pennisetum glaucum	22.3	19.4	16.8	14.5	12.3	17.1	7.70	6.67	6.20	5.77	4.63	6.19
Sorghum bicolor	22.3	18.8	14.7	12.2	10.7	15.7	7.77	6.30	6.70	5.90	3.80	6.09
Panicum sumatrense	16.7	14.2	11.8	9.5	8.30	12.1	7.53	6.90	6.43	5.90	4.40	6.23
Paspalum scrobiculatum	21.9	18.7	15.6	13.6	7.83	15.5	6.50	6.90	6.37	5.90	4.40	6.01
Panicum miliaceum	19.4	16.7	15.4	14.8	13.3	15.4	6.53	6.10	5.70	5.20	4.80	5.67
Setaria italica	16.7	14.8	12.6	11.8	9.60	13.1	6.80	6.30	5.80	5.00	4.50	5.68
Echinochloa frumentacea	21.6	18.8	16.5	14.2	11.2	16.5	6.90	6.40	5.33	4.80	4.20	5.53
Sesamum indicum	16.7	15.6	13.8	11.8	9.67	13.5	7.20	6.73	5.83	5.00	4.47	5.85
Fodder *Zea mays*	37.3	33.9	31.5	26.7	22.7	30.4	8.60	7.87	7.07	6.40	5.77	7.14
Fodder *Sorghum bicolor*	23.3	19.4	17.3	14.4	11.3	17.1	7.10	6.67	6.20	5.70	4.90	6.11
Mean	26.1	23.2	20.6	17.7	14.5	20.4	8.43	7.77	7.04	6.31	5.33	6.97
	C	S	CxS				C	S	CxS			
SEd	0.83	0.44	1.86				0.54	0.29	1.23			
CD (P=0.05)	1.64	0.86	3.68				1.10	0.57	2.42			

* C- crops S- Saline – Sodic soils NSS- Non saline sodic soils SS- Saline- Sodic Soils

Simliar to plant height, higher root length was observed in non-saline sodic soil than in saline-sodic soils and increasing saline - sodicity results in 7.8 to 36.7 per cent reduction in root growth. Higher mean root length was recorded in *Oryza sativa* (11.5cm) followed by *Zea mays* (10.9 cm), *Eleusine coracana* (10.6cm) fodder *Zea mays* (7.14cm) and *Helianthus annuus* (6.94 cm). Very poor root length was associated with the crops viz., *Panicum miliaceum, Setaria italica and Echinochloa frumentaceae* which indicated their susceptibility to saline-sodicity. The interaction between various levels of saline-sodicity and crops were found significant.

Plant dry biomass production

Saline- sodicity significantly reduced the plant dry biomass in all the crops and the reduction in plant dry biomass production was marked with increasing saline - sodicity levels (15.8 to 59.2 per cent). The data on plant dry biomass of crops under non saline sodic soil and different saline- sodic soils is furnished in Table 3. In the non-saline-sodic soil, almost all the crops produced higher dry biomass while at higher level of saline - sodicity (8-16 dSm^{-1}) all the crops were proved to be sensitive with higher per cent biomass reduction (50-60%). However the crops viz., *Zea mays* (0.97 g $plant^{-1}$), *Eleusine coracana* (0.91 g $plant^{-1}$), *Gossypium hirsutum* (0.81 g $plant^{-1}$), fodder *Zea mays* (0.71 g $plant^{-1}$) and *Helianthus annuus* (0.68 g $plant^{-1}$) showed maximum salt tolerance by registering lesser per cent biomass reduction. The small millets like *Panicum miliaceum*, *Panicum sumatrense*, *Paspalum scrobiculatum* and *Setaria italica* were found to be sensitive to various levels of saline-sodicity by registering very low dry biomass (<0.31 g $plant^{-1}$ Figure 1). Though the dry biomass production of crops was reduced in various saline-sodic soils, maximum reduction was observed in the soil having an EC of 8-16 dSm^{-1}.

Table 3: Effect of native saline-sodicity on plant dry biomass production of crops

Crops	**DMP (g)**					
	NSS	**SS1**	**SS2**	**SS3**	**SS4**	**Mean**
Oryza sativa	0.71	0.61	0.56	0.38	0.25	0.50
Zea mays	1.28	1.10	1.02	0.89	0.57	0.97
Eleusine coracana	1.25	1.05	0.85	0.73	0.65	0.91
Helianthus annuus	0.97	0.81	0.70	0.54	0.40	0.68
Gossypium hirsutum	1.13	1.03	0.82	0.64	0.42	0.81
Amaranthus cruenthus	0.65	0.57	0.50	0.37	0.28	0.47
Sesbania bispinosa	0.85	0.70	0.62	0.49	0.30	0.59
Medicago sativa	0.79	0.74	0.58	0.41	0.32	0.57
Pennisetum glaucum	0.72	0.57	0.51	0.42	0.31	0.51
Sorghum bicolor	0.68	0.61	0.51	0.35	0.25	0.48
Panicum sumatrense	0.45	0.32	0.30	0.27	0.20	0.31
Paspalum scrobiculatum	0.42	0.31	0.27	0.21	0.17	0.28
Panicum miliaceum	0.44	0.32	0.26	0.17	0.12	0.26
Setaria italica	0.50	0.37	0.25	0.19	0.15	0.29
Echinochloa frumentacea	0.46	0.35	0.31	0.17	0.16	0.29
Sesamum indicum	0.72	0.53	0.42	0.36	0.27	0.46
Fodder *Zea mays*	0.95	0.91	0.68	0.58	0.44	0.71
Fodder *Sorghum bicolor*	0.79	0.65	0.51	0.43	0.28	0.53
Mean	0.76	0.64	0.54	0.42	0.31	0.53
	C	S	CxS			
SEd	0.04	0.02	0.10			
CD (P=0.05)	0.10	0.03	0.15			

* C- crops S- Saline – Sodic soils NSS- Non saline sodic soils SS- Saline- Sodic Soils

Plant elemental concentrations

Saline - Sodicity caused significant increase in Na^+ and Cl^- absorption in the plant tissues in contrary to K^+, Ca^{2+} and Mg^{2+} concentration which decreased with increasing saline-sodicity (Table 4 and 5). The results showed a substantial increase in Na^+ and Cl^- content in all the crops with increasing saline- sodicity (35.6 and 21.2 per cent respectively). Higher mean Na^+ and Cl^{-1} content was recorded in calcareous saline sodic soil having an EC of 8- 16 dSm^{-1}. The increase in mean absorption of these osmolytes was 62.2 and 49.2 per cent respectively for Na^+ and Cl^- ions than in non-saline sodic soil. At higher saline -sodicity also, *Zea mays* recorded higher mean Na^+ (1.16 %) and Cl^- concentration (1.15%). This was followed by *Eleusine coracana* and *Helianthus annuus.* The lowest concentration of Na^+ and Cl^- ions were noticed with *Setaria italica.*

Table 4: Effect of native soil saline-sodicity on K^+ and Ca^{2+} concentrations in crops

Crops	K content (%)						Ca content (%)					
	NSS	SS1	SS2	SS3	SS4	Mean	NSS	SS1	SS2	SS3	SS4	Mean
Oryza sativa	0.87	0.77	0.86	0.82	0.73	0.81	0.59	0.48	0.42	0.36	0.36	0.44
Zea mays	0.95	0.88	0.97	0.90	0.73	0.89	0.65	0.59	0.53	0.45	0.38	0.52
Eleusine coracana	0.98	0.94	0.83	0.80	0.72	0.85	0.66	0.61	0.55	0.43	0.42	0.53
Helianthus annuus	1.01	0.94	0.85	0.88	0.70	0.88	0.60	0.57	0.53	0.44	0.41	0.51
Gossypium hirsutum	0.95	0.90	0.83	0.79	0.75	0.84	0.69	0.65	0.57	0.47	0.39	0.55
Amaranthus cruenthus	0.86	0.77	0.71	0.66	0.58	0.72	0.66	0.61	0.49	0.45	0.43	0.53
Sesbania bispinosa	0.88	0.77	0.73	0.69	0.54	0.72	0.76	0.60	0.50	0.39	0.35	0.52
Medicago sativa	0.94	0.85	0.79	0.72	0.63	0.79	0.48	0.45	0.33	0.28	0.27	0.36
Pennisetum glaucum	0.62	0.52	0.49	0.46	0.44	0.51	0.29	0.26	0.20	0.18	0.15	0.22
Sorghum bicolor	0.53	0.47	0.45	0.42	0.40	0.45	0.27	0.26	0.23	0.19	0.16	0.22
Panicum sumatrense	0.52	0.48	0.37	0.34	0.32	0.41	0.39	0.26	0.24	0.18	0.17	0.25
Paspalum scrobiculatum	0.42	0.37	0.35	0.33	0.31	0.36	0.31	0.29	0.24	0.19	0.17	0.24
Panicum miliaceum	0.35	0.33	0.31	0.31	0.26	0.31	0.30	0.27	0.23	0.18	0.16	0.23
Setaria italica	0.39	0.34	0.31	0.30	0.27	0.32	0.35	0.31	0.23	0.18	0.15	0.24
Echinochloa frumentacea	0.67	0.57	0.48	0.43	0.40	0.51	0.32	0.30	0.22	0.16	0.14	0.23
Sesamum indicum	0.53	0.49	0.46	0.43	0.41	0.46	0.37	0.36	0.31	0.26	0.17	0.29
Fodder *Zea mays*	0.84	0.81	0.74	0.66	0.62	0.73	0.69	0.63	0.53	0.36	0.31	0.50
Fodder *Sorghum bicolor*	0.50	0.48	0.42	0.40	0.38	0.44	0.76	0.60	0.56	0.38	0.35	0.53
Mean	0.71	0.65	0.61	0.57	0.51	0.61	0.51	0.45	0.38	0.31	0.27	0.38
	C	S	CxS				C	S	CxS			
SEd	0.03	0.01	0.10				0.02	0.01	0.05			
CD (P=0.05)	0.05	0.03	0.12				0.04	0.02	0.09			

* C- crops S- Saline – Sodic soils NSS- Non saline sodic soils SS- Saline- Sodic Soils

Table 5: Effect of native soil saline-sodicity on Na^+ and Cl^- concentrations in crops

Crops	Na content (%)						Cl content (%)					
	NSS	SS1	SS2	SS3	SS4	Mean	NSS	SS1	SS2	SS3	SS4	Mean
Oryza sativa	0.69	0.87	0.96	1.08	1.24	0.97	0.73	0.92	1.02	1.12	1.21	1.00
Zea mays	0.81	1.01	1.15	1.35	1.47	1.16	0.83	1.08	1.20	1.27	1.36	1.15
Eleusine coracana	0.85	0.97	1.09	1.26	1.37	1.11	0.74	1.01	1.09	1.13	1.28	1.05
Helianthus annuus	0.70	0.87	1.02	1.16	1.23	1.00	0.72	0.98	1.00	1.10	1.24	1.01
Gossypium hirsutum	0.66	0.84	0.86	1.00	1.15	0.90	0.70	0.89	0.92	1.04	1.09	0.93
Amaranthus cruenthus	0.75	0.97	1.02	1.12	1.25	1.02	0.71	0.95	1.03	1.09	1.14	0.98
Sesbania bispinosa	0.78	1.01	1.05	1.10	1.15	1.02	0.71	0.94	0.96	1.05	1.08	0.95
Medicago sativa	0.63	0.84	0.96	1.06	1.18	0.93	0.64	0.89	0.94	1.01	1.05	0.91
Pennisetum glaucum	0.62	0.71	0.76	0.85	0.91	0.77	0.52	0.62	0.75	0.78	0.80	0.69
Sorghum bicolor	0.61	0.70	0.74	0.81	0.85	0.74	0.55	0.61	0.65	0.68	0.70	0.64
Panicum sumatrense	0.62	0.65	0.73	0.79	0.81	0.72	0.61	0.68	0.76	0.80	0.81	0.73
Paspalum scrobiculatum	0.54	0.59	0.60	0.76	0.81	0.66	0.53	0.62	0.74	0.77	0.79	0.69
Panicum miliaceum	0.47	0.52	0.60	0.60	0.65	0.57	0.62	0.69	0.74	0.77	0.80	0.72
Setaria italica	0.37	0.48	0.55	0.68	0.77	0.57	0.56	0.64	0.70	0.73	0.75	0.68
Echinochloa frumentacea	0.44	0.49	0.56	0.69	0.73	0.58	0.59	0.65	0.71	0.74	0.76	0.69
Sesamum indicum	0.46	0.56	0.60	0.62	0.77	0.60	0.50	0.66	0.72	0.75	0.77	0.68
Fodder *Zea mays*	0.43	0.55	0.64	0.69	0.73	0.61	0.71	0.87	0.90	0.93	0.95	0.87
Fodder *Sorghum bicolor*	0.49	0.54	0.60	0.64	0.83	0.62	0.65	0.78	0.84	0.87	0.89	0.81
Mean	0.61	0.73	0.81	0.90	0.99	0.81	0.65	0.80	0.87	0.92	0.97	0.84
	C	S	CxS				C	S	CxS			
SEd	0.03	0.02	0.10				0.02	0.01	0.10			
CD (P=0.05)	0.10	0.03	0.14				0.04	0.02	0.10			

* C- crops S- Saline – Sodic soils NSS- Non saline sodic soils SS- Saline- Sodic Soils

In contrary to Na^+ and Cl^- ions, the concentration of K^+ and Ca^{2+} ions declined with increasing saline-sodicity as a result of competita interaction. The reduction in concentration varied from 8.45 to 28.2 per cent for K^+ and 11.8 to 47.05 per cent for Ca^{2+} ions than in the non-saline- sodic soil. Higher mean Ca^{2+} content was recorded in *Gossypium hirsutum* (0.55 per cent) followed by *Eleusine coracana =Amaranthus cruentus = Sorghum bicolor > Zea mays*. The K^+ ions concentration was higher in *Zea mays (0.89 per cent)* followed by *Helianthus annus* and *Eleusine coracana.* The lowest K^+ and Ca^{2+} ions content was noticed in small millets viz, *Panicum miliaceum and Setaria italica.*

Phyto-reclamation potentials of crops

The potentials of various crops in ameliorating calcareous saline – sodic soils was evaluated by determining their tolerance in terms of plant biomass production and quantifying the salt removal potentials. The biomass production of crops in non-saline sodic soil was compared with the saline sodic soils and the crops having lesser reduction in biomass production with increasing saline-sodicity was chosen as tolerant crops. In this way, the mean dry biomass recorded with various crops indicated that *Zea mays* and *Eleusine coracana* produced higher biomass in the entire saline - sodic soils environment with lesser reduction in biomass (14 to 48 %) than the normal soil.

The amount of Na^+ and total salts removed through the harvested biomass was computed by employing the equation proposed by Qadir *et al.* (2003) [12] as below:

$$S_{\text{ion removal}} = [(S_{\text{ion concentration}})\,(S_{DW})/(10^3)] \,/\, MW_{\text{ion}}$$

Where

$S_{\text{ion removal}}$ is ion removed through harvest (mmol pot^{-1}),

$S_{\text{ion concentration}}$ is ion concentration in harvested plant part (mg kg^{-1}),

S_{DW}- is plant dry weight (g pot^{-1}) and

MW_{ion} is molecular weight of ion.

The Na^+ and total salts removal by the crops in calcareous saline- sodic soils was calculated and given in Table 6. The data revealed that, *Zea mays* and *Eleusine coracana* removed higher amount of Na^+ and total salts from the soil. The increase in Na^+ and total salt removal was 6.50 to 7.50 fold in *Zea mays* and in *Eleusine coracana* it was 5.8 to 6.7 fold increase in Na^+ and total salt removal when compared to the sensitive *Panicum miliaceum* (Figure 2 & 3). The crops *Panicum miliaceum* and *Setaria italica* were found to be highly sensitive to saline- sodicity by registering poor biomass, Na^+ and total salt removal potentials.

Table 6: Effect of native soil saline-sodicity on total salt and Na removal by crops

Crops	Na removal (mg g^{-1})						Total salt removal (mg g^{-1})					
	NSS	SS1	SS2	SS3	SS4	Mean	NSS	SS1	SS2	SS3	SS4	Mean
Oryza sativa	4.94	5.33	5.41	4.09	3.16	4.59	0.14	0.11	0.11	0.06	0.04	0.09
Zea mays	10.4	11.1	11.8	12.0	8.44	10.8	0.42	0.36	0.35	0.29	0.14	0.31
Eleusine coracana	10.7	10.3	9.33	9.16	8.93	9.68	0.39	0.33	0.23	0.19	0.16	0.26
Helianthus annuus	6.82	7.07	7.20	6.26	4.98	6.47	0.24	0.20	0.17	0.12	0.07	0.16
Gossypium hirsutum	7.52	8.68	7.12	6.35	4.87	6.91	0.30	0.29	0.19	0.13	0.07	0.20
Amaranthus cruenthus	4.93	5.56	5.17	4.11	3.53	4.66	0.13	0.11	0.09	0.06	0.04	0.09
Sesbania bispinosa	6.68	7.08	6.54	5.38	3.47	5.83	0.20	0.16	0.13	0.09	0.04	0.12
Medicago sativa	5.02	6.26	5.63	4.33	3.84	5.01	0.15	0.15	0.11	0.06	0.04	0.10
Pennisetum glaucum	4.51	4.08	3.94	3.55	2.86	3.79	0.09	0.06	0.06	0.04	0.03	0.06
Sorghum bicolor	4.21	4.31	3.84	2.81	2.13	3.46	0.08	0.07	0.05	0.03	0.02	0.05
Panicum sumatrense	2.85	2.11	2.25	2.11	1.63	2.19	0.04	0.02	0.02	0.02	0.01	0.02
Paspalum scrobiculatum	2.33	1.87	1.67	1.57	1.38	1.76	0.03	0.02	0.02	0.01	0.01	0.02
Panicum miliaceum	2.12	1.70	1.62	0.99	0.78	1.44	0.03	0.02	0.02	0.01	0.00	0.02
Setaria italica	1.90	1.81	1.43	1.27	1.16	1.51	0.04	0.02	0.01	0.01	0.01	0.02
Echinochloa frumentacea	2.09	1.74	1.79	1.16	1.17	1.59	0.04	0.03	0.02	0.01	0.01	0.02
Sesamum indicum	3.37	2.98	2.57	2.20	2.09	2.64	0.08	0.05	0.04	0.03	0.02	0.04
Fodder *Zea mays*	4.15	5.02	4.41	3.97	3.22	4.15	0.18	0.18	0.12	0.08	0.05	0.12
Fodder *Sorghum bicolor*	3.94	3.54	3.11	2.73	2.33	3.13	0.11	0.08	0.05	0.04	0.02	0.06
Mean	4.92	5.03	4.71	4.11	3.33	4.42	0.15	0.13	0.10	0.07	0.04	0.10
	C	**S**	**CxS**				**C**	**S**	**CxS**			
SEd	0.41	0.22	0.93				0.01	0.01	0.03			
CD (P=0.05)	0.82	0.43	1.83				0.03	0.01	0.05			

* C- crops S- Saline – Sodic soils NSS- Non saline sodic soils SS- Saline- Sodic Soils

Discussions

Crops responded varyingly to saline - sodic conditions and increasing levels of saline - sodicity showed detrimental effect on plant growth and biomass production of all the crops. The growth performance of *Zea mays,* Fodder *Zea mays* and *Eleusine coracana* was comparatively better as compared to others. Similar better performance by sorghum genotypes was reported by Yakubu *et al.* (2006) [18]. However the crops such as *Setaria italica* and *Panicum sumatrense* registered poor growth attributes and biomass production. The reduced plant growth with increasing saline - sodicity could be ascribed to the interference of nutrient absorption and physiological water stress created by high salt concentrations in the root zone (Folorunso *et al.*, 2005; Hajer *et al.*, 2006; Azene Tesfaye *et al,* 2014) [6, 10, 3]. Many reports suggested that, the crops with least reduction in biomass production and plant growth were considered as tolerant while those with higher reduction in biomass production and plant growth were categorized as sensitive ones (Ahmad and Khan, 2010; Li *et al,* 2010) [1, 11]. Hence a relatively lesser biomass and growth reduction observed in *Zea mays,* Fodder *Zea mays* and *Eleusine coracana* could be ascribed to their successful maintenance of cell turgor under saline- sodic conditions (Sahid *et al,* 2012).

Saline - Sodicity caused significant increase in Na^+ and Cl^- absorption in the plant tissues in contrary to K^+ and Ca^{2+} concentration which decreased with increasing saline-sodicity. The Na^+ and Cl^- content in all the test crops increased with increasing soil saline- sodicity ascribed to higher salt concentration in the soils which led to increase in Na^+ and Cl^- concentration in plants. Significant negative relationship existed between Na^+ and K^+ and Ca^{2+} which suggested that Na exerts inhibitory effect on the absorption of K^+ and Ca^{2+} by crop varieties. Similar results were reported by Sahid *et al,* (2012) and Azene Tesfaye *et al,* (2014) [3].

Higher Na^+ and Cl^- concentration was recorded by *Zea mays* followed by *Eleusine coracana* and *Helianthus annuus*. Even though Na^+ and Cl^- concentrations were quite high in these plants, no visual toxicities were observed during the growth period. The lowest concentration of Na^+ and Cl^- ions were noticed with *Setaria italica.*

Plant tissue concentration of K^+ and Ca^{2+} ions declined with increasing saline – sodicity and the magnitude of reduction was higher for Ca^{2+} ions (>40%) than K^+ ions in plants (>25%). Similar negative effect of saline-sodicity on Ca^{2+} and Mg^{2+} absorption in saline environment was reported by many researcher (Sarwar and Adhraf, 2003). Higher mean Ca^{2+} content was recorded in *Gossypium hirsutum* (0.55 per cent) followed by *Eleusine coracana =Amaranthus cruentus = Sorghum bicolor* > *Zea mays*. The K^+ ions concentration was higher in *Zea mays* (0.89 %) followed by *Helianthus annus* and *Eleusine coracana.* The lowest K^+ and Ca^{2+} ions content was noticed in the small millets viz, *Panicum milliaceum and Setaria italica* which indicated their lesser growth and response to saline-sodicity and higher susceptibility. Higher Ca^{2+}, Mg^{2+} and K^+ concentration in plants were observed in non-saline sodic soil and it was the reverse in case of Na^+ and Cl^- concentration. The order of higher plant tissue concentration was $Na^+ > Cl^- > K^+ > Ca^{2+} > Mg^{2+}$.

Electrical conductivity values of the saline-sodic soils and non-saline-sodic soil were positively affected with the crop gown. When the values were compared in both before and after sowing, significantly decreases were observed in all soils. The lowest EC was recorded with *Zea mays* and *Eleusine coracana* this may be due to the higher ions uptake of the crops (Yu *et al.,* 2010) [19]. The Na^+ and salt removal potentials of various crops in ameliorating the calcareous saline - sodic soils were evaluated by determining the biomass production and salt removal potentials. The biomass production of crops in non-saline sodic soil was higher than the saline -sodic soils. Higher Na^+ and salt removal potentials were observed with *Zea mays* and *Eleusine coracana* in various saline - sodic soils. The crops *Panicum milliaceum* and *Setaria italica* were found to be highly sensitive to saline-sodicity by registering poor biomass, Na^+ and total salt removal potentials (Qadir *et al.,* 2003) [12].

Native calcite was get dissolute by the crops grown in the various calcareous saline-sodic soils. Irrespective of the crops all are showed positive effect on native calcite dissolution. Amoug the crops growth *Zea mays*, *Eleusine coracana* and *Helianthus annus* showed better dissolution percentage. This may be due to the higher secretion of organic acid l and also by the root respiration CO_2 will get emitted in higher amount by this formation of carbonic acid will take place these acids can dissolute the calcite from the soil (Gharaibeh *et al.,* 2011) [7].

Conclusion

The present investigation concludes that, increasing levels of soil saline- sodicity decreased the plant biomass production and growth of all the crops than in the normal soils. Significant linear increase in the absorption of Na^+ and Cl^- ions with increasing saline-sodicity was observed in all the crops. But the concentration of Ca^{2+} and K^+ showed a reverse trend with saline - sodicity in the plant tissues. Though the biomass production decreased with increasing saline-sodicity, significantly higher biomass of *Zea mays* and *Eleusine coracana* indicated their tolerance to saline sodic situations. Further higher Na^+ and salt removal potentials of these crops indicated their capabilities to survive and reclaim the saline - sodic soils. However, further research is needed to confirm their efficiencies under field conditions in order to authenticate these findings.

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References

1. Ahmad MZ, Khan MA. Tolerance and recovery responses of playa halophytes to light, salinity and temperature stresses during seed germination. Flora. 2010; 205:764-771.
2. Arfan M, Athar HR, Ashraf M. Does exogenous application of salicylic acid through the rooting medium modulate growth and photosynthetic capacity in two differently adapted spring wheat cultivars under salt stress. J. Plant Physiol. 2007; 164:685-694.
3. Azene Tesfaye, Yohannes Petros, Habtamu Zeleke. Screening Some Accessions of Lentil (*Lens Culinaris* M.) For Salt Tolerance at Germination and Early Seedling Stage in Eastern Ethiopia. Intl. J. tech. enhancements and emerging engg. 2014; 2:(8)106
4. Bhantana Parashuram, Lazarovitch Naftali. Evapotranspiration, crop coefficient and growth of two young pomegranate (*Punica granatum* L.) varieties under salt stress. Agrl Water Manage. 2010; 30:38-42
5. Cambrolle J, Redondo Gomez S, Mateos-Naranjo E, Luque T, Figueroa ME. Physiological responses to salinity in the yellow-horned poppy, *Glaucium flavum*. Plant Physiol Biochem. 2011; 49:186-194.
6. Folorunso OA, Chiroma AM, Abdullahi D. Influence NaCl salinity on soil properties and early growth of groundnut (*Arachis hypogaea* L.) Environtropica. 2005; 2:91- 99.
7. Gharaibeh MA, Eltaif NI, Albalasmeh AA. Reclamation of highly calcareous saline sodic soil using *Atriplex halimus* and by-product gypsum. Int J Phytoremediation. 2011; 13:873-883.
8. Grewa HS. Water uptake, water use efficiency, plant growth and ionic balance of wheat, barley, canola and chickpea plants on a sodic vertosol with variable subsoil NaCl salinity. Agri Water Manage. 2010; 97:148-156.
9. Grieve AM, Prior DL, Bevington BK. Long-term effect of saline irrigation water on growth, yield, and fruit quality of Valencia orange trees. Plant and Soil. 2007; 45:313-317.
10. Hajer AS, Malibari AA, Al-Zahrani HS, Almaghrabi OA. Responses of three tomato cultivars to sea water salinity: Effect of salinity on the seedling growth. Afr. J Biotechnol. 2006; 5:855-861
11. Li R, Shi F, Fukuda K. Interactive effects of salt and alkali stresses on seed germination, germination recovery, and seedling growth of a halophyte *Spartina alterniflora* (Poaceae). S Afr J Bot. 2010; 76:380-387.
12. Qadir M, Steffens D, Yan F, Schubert S. Sodium removal from a calcareous saline-sodic soil through leaching and plant uptake during phytoremediation. Land Degrad. Dev. 2003; 14:301-307.
13. Salih Aydemir, Halime Sunger. Growth response and ameliorative effect of a forage plant (*Festuca arundinacea*) in calcareous saline-sodic soils. Afr. J Agrl

Res. 2012; 7(5):802-809.
14. Sarwar G, Asheaf MY. Genetinc variability of some primitive bread wheat vartieties to salt tolerance. Pakisthan. J Bot. 2003; 35(5):771-777
15. Sardouie-Nasab S, Mohammadi-Nejad GH, Nakhoda B. Field Screening of Salinity Tolerance in Iranian Bread Wheat Lines. Crop Sci. 2014; 54:1489-1496.
16. Shahid MA, Pervez MA, Balal RM, Abbas T, Ayyub CM, Mattson NS *et al*. Screening of pea (*Pisum sativum* L.) genotypes for salt tolerance based on early growth stage attributes and leaf inorganic osmolytes. Australian. J.Crop Sci. 2012; 6(9):1324-133.
17. Siringam K, Juntawong N, Cha-um S, Boriboonkaset T, Kirdmanee C. Salt tolerance enhancement in indica rice (*Oryza sativa* L. spp. indica) seedlings using exogenous sucrose supplementation. Plant Omics J. 2012; 5:52-59.
18. Yakubu H, Usman H, Chiroma AM. Screening of Sorghum Varieties for Salt tolerance in a sandy loam soil of Borno State, Nigeria. Nigerian J Exp. and Appl. Biol. 2006; 7(1):49-54.
19. Yu J, Wang Z, Meixner FX, Yang F, Wu H, Chen X. Biogeochemical Characterizations and Reclamation Strategies of Saline Sodic Soil in Northeastern China. Soil, Air, Water. 2010; 38(11):1010-1016.