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A Study on *Salicornia* (*S. brachiata* Roxb.) in Salinity Ingressed Soils of India*

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Abstract: *Salicornia* experiments on saline ingressed coastal soils were conducted in field during July-Aug (*Kharif* season) of 2003-04 at CSMCRI's experimental site, Hathab on native species to investigate make improvements in agronomic criteria and allow species cultivation sustainable so to recover its' high valued vegetable salt and oil per unit of salt affected area. An application of N upto 100 kg ha^{-1} had significantly increased the seed yield (29 and 87%) and plant biomass (29 and 51%), over 75 and 0 kg N ha^{-1}, respectively. Plant characters like canopy, spike length, number of segments and harvest index were also found increased with the increase in N application. An application of 75 kg P_2O_5 ha^{-1} was also found significant with an achievement in higher seed yield production (48%) and number of spike segments (43%) over the control. The interaction study between the applied doses of N×P was found significant at highest fertilizer levels (N_2×P_2) and produced maximum seed yield over the control but remain and at par in case of plant biomass. The plant nitrogen content in biomass (spike+seed) though found increased with N application but has remained at par in case of P application. Nitrogen and potassium content and uptakes were found increased significantly with N application. The plant density had a significant effect on yield, biomass and other important yield attributes. Plant canopy increased significantly during different phases of growth. The potential usefulness of *S. brachiata* for agricultural producers in coastal semi-arid zones has been shown elsewhere; suggest that the establishment and growth of this halophyte can be experimentally improved using proper fertilization and optimum density.

Key words: Halophytes, plant density, *Salicornia brachiata* (Roxb.)

Introduction

Erratic precipitation pattern and low average rainfall (≈350 mm) are the characteristics of semi-arid west coast in India. Agricultural activities are, therefore, dependent on wells. Unfortunately, water extraction in excess of the rate of replacement and the inappropriate land and water use had accentuated salinization ingress of agriculture soils, which has now become major problem in the production of traditional crops (GEC, 2001; SAGAR, 1981). Production alternatives include development of salt-tolerant plants that already exists in salt flat areas and focusing on those that might make desirable crops (Ungar, 2000). This is especially worth in coastal area where arable soils gets frequently inundated and ingressed with sea water salinity (GEC, 2001; SAC (ISRO), 1992).

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An obligate halophyte *Salicornia brachiata,* Roxb., (Chenopodiaceae) is inhabited to salt flats of Arabian Sea coast and costal soil sustained environments (Sanish *et al*., 1991). The annual leafless halophyte has green, jointed succulent stems that forms terminal fruit bearing spikes, in which the seeds are borne (Glenn *et al*., 1994; Gallawa, 1996). *Salicornia* seed yields special quality oil, highly poly-unsaturated, similar to safflower oil is rich in linoleic acid. This halophytic shrub of coastal mud flats is potentially high biomass producing marine ecosystem, recently innovated as a source of high valued vegetable salt and for bioactives' potentials besides its seed oil for industrial use (Ghosh *et al*., 2003; Rathod *et al*., 2004). This plant was identified from many halophyte species tested for possible domestication because of its field crop potential not only as an oilseed plant, but as a new bio material for vegetable salt and herbal drug potentials (Glenn *et al*., 1991, 1995; CSMCRI, 2003; Mudie *et al*., 2005).

In the wild, productivity of *Salicornia* seeds is very low (around 1-3 g/plant) because of high competition for space, nutrition and the moisture. The optimum plant per unit area and appropriate doses of fertilization are most important parameters for increased crop productivity. No systematic work has been attempted so far. Hence, an attempt is made here to determine and standardize an alternate cropping model for utilization of saline wastelands and saline water use and evaluate productive efficiency of *Salicornia* under highly saline ingressed coastal soils and understand the influence of agronomic traits through planting geometry and fertilization on growth, yield and biomass production.

Materials and Methods

Study Site

The investigations were carried out during the year 2003-2004 at CSMCRI's halophytic research farm on the southwestern coast of the Gulf of Cambay at Hathab (Bhavnagar, India 20° 35' North, 072° 16' East), where the annual halophyte *Salicornia brachiata* has been put under long term seawater-irrigation cultivation. The ground water salinity during the entire experimental periods fluctuated from as low as 8000 (Sep/Oct.) to 31000 (Jan/Feb.) ppm in the well (200 m away from sea) dug for irrigation purpose and used in the course of growth period of *Salicornia* species. Total six saline irrigations per month were applied with hose method of irrigation to each experiment for achieving optimum growth and fulfill its water requirements. Soil at the site is silty clay and saline in nature having pH: 8.53, EC: 10.4 to 13.39 dS m^{-1} and organic carbon 0.54%, available phosphorus and potassium were 24.5 and 1737.5 kg ha^{-1}, respectively (Table 1). During the cropping season, i.e., July 2003 to March 2004, lowest minimum temperature was 12°C (January), maximum temperature reached 42°C (June) and relative humidity was always more than 50%. *Salicornia brachiata* flowered in mid-winter and was senescent by early January. Irrigations were terminated in mid-February.

Studies of Fertilizer Application

All the treatment combinations of three levels of N (0, 75 and 100 kg ha^{-1}) and P (0, 50 and 75 kg ha^{-1}) were tried in Randomized Block Design. The treatments were replicated thrice adopting a micro-plot size 12.5 m^2. Nitrogen was applied through Urea in split as basal, 45 and 60 days after

Table 1: Soil characteristic of experimental site

					Available nutrient (kg ha^{-1})			Cation in saturation extract (mg L^{-1})			
pH	Sand (%)	Silt (%)	Clay (%)	EC (dS m^{-1})	O.C. (%)	P_2O_5	K_2O	Na	K	Ca	Mg
8.53	11.15	43.30	45.80	10.4-13.39	0.54	24.5	1737.5	161.1	1.18	12.2	69.25

sowing and phosphorus through SSP (Single Super Phosphate) as a basal dressing. Forty five days old seedlings grown in the same soil were transplanted (50×25 cm) in the field during 1st week of August 2003. At vegetative stage, 10 plants selected randomly for collecting all the morphological and harvested individual plant wise for yield data. Harvest index was calculated using the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield (kg ha}^{-1}) \times 100}{\text{Total plant biomass (kg ha}^{-1})}$$

Sampling Procedures

Soil within the each plot was sampled from 0 to 15 cm, a depth within the plant rooting zone and the amended residues. After harvesting *Salicornia* in February, five soil cores from each plot were taken in an X pattern with a 4.5 cm diameter bucket auger to a depth of 15 cm. All soil samples were well mixed, dried at 45°C and powdered. The dried soils (<2 mm) were digested with hydrofluoric and perchloric acids at 200°C (Hess, 1976) and finally dissolved in hydrochloric acid and analyzed for Na, K, Ca, Mg using atomic absorption spectrophotometer (GBC 932+). While, OC% was determined by using the method of Walkley (1947) and available P_2O_5 by Olsen *et al*. (1954). For the determination of EC and pH, potentiometer was used.

Nutrient Content

The nutrient content study was made analyzing the mature spikes, contributing ~75% of the plant dry biomass and having in cavities the tiny seeds filled in at the time of maturity. The biomass (spike+seed) after drying were digested with diacid mixture (HNO_3 + $HClO_4$, 4:1) and analyzed for P by ammonium molybdate vandate yellow colour method and N was determined by Kjeldahl method.

Studies of Plant Density

Treatments of plant density resorted by direct seeding of *Salicornia brachiata* for four densities viz., 800, 571, 400 and 278 plants 10 m^{-2} and are termed as T_1 T_2 T_3 and T_4, respectively. All treatments were replicated thrice in randomized block design. Five plants were randomly selected from every treatment for measuring the yield and its attributing characters at the time of harvesting. All plots were fertilized with Urea for 100 kg N ha^{-1} and Di-ammonium Phosphate at the rate of 75 kg P_2O_5 ha^{-1} for the normal crop growth.

Growth Pattern Observation

Being an annual halophyte and long duration crop, *Salicornia* has three important phases of its life-cycle viz., vegetative, flowering and seed setting. Seedlings with equal and homogenous growth were transplanted after 45 days in micro-plots in the same saline soil. Hundred plants were selected during 2002-03 and 2003-04 for observing its two important yields attributes which has major impact on species seed yield. These two attributes viz., plant canopy and plant height were selected for the purpose and observations were recorded during above three important phases attained at 90, 120 and 165 days after transplanting of the seedlings.

Results and Discussion

Effect of Fertilizer Application

Clearly *S brachiata* is a potential crop whose vegetable parts and oil-containing seed by-products Sare of special interest. Total absolute seed yield *vis a vis* a plant biomass are the most important parameters to evaluate. The results here in the present study for individual and interaction effect of N and P on yield, biomass and other yield attributes are described individually.

Effect of Nitrogen

Being a salt flat halophytic species, *Salicornia* has high N affinity and requirements. With an application of N up to 100 kg ha^{-1} increased the seed yield, number of main braches, number of segments, number of spikes per branch, spike length and harvest index, but significantly positive response was obtained for seed yield and number of spikes per branch which was at 75 kg ha^{-1}, while it was found at par with 100 kg N ha^{-1}. *Salicornia* seed yield (918.2 kg ha^{-1}) was obtained highest at 100 kg N ha^{-1} dose recording an increase of 18 and 86 per cent higher yield over 75 kg N ha^{-1} and control, respectively. Several studies on the nutritional conditions necessary to faster growth of *S. bigelovii* have identified the need for extremely high quantities of nitrogen (N) fertilizer (Mota, 1996; Rueda-Puente *et al*., 2004). In case of biomass production, 100 kg N ha^{-1} found significantly high over control with an increase of 51% (Table 2). Similar results wee obtained in studies with *S. bigelovii* (Mota 1990, 1999; Covin and Zedler, 1988; Loveland and Ungar, 1983; Glenn *et al*., 1991; Ungar, 2000).

Effect of Phosphorus

Increasing doses of phosphorus up to 75 kg ha^{-1} increased the seed yield and spikes per branch significantly. Moreover, same was found significantly higher over control and 50 kg ha^{-1} levels. The phosphorus application on *Salicornia* produced highest seed yield at 75 kg P_2O_5 ha^{-1} dose (846 kg ha^{-1}) with an increase of 48% of seed production over control whereas, the biomass production per hectare did not show any specific trends over the different doses of applied phosphorus (Table 3).

In case of interaction between the nutrients, the seed yield got highly influenced at highest level of fertigation i.e., $N_2 \times P_2$ and found significantly high over control (Table 4) whereas it is found non-significant for plant biomass production.

Nutrient Content and its Uptake

Application of N significantly increases the content of nitrogen in *Salicornia* biomass (spikes+ seed), spike is a scale like structure. Consequently, the nitrogen uptake in *Salicornia* biomass increased significantly mainly as a result of higher plant biomass and improvement in N content. The magnitude of increase in potassium uptake was more as results of symbiosis with nitrogen. The K uptake by *Salicornia* biomass (spikes + seed) increased by 65 and 91% with respective addition of 75 and 100 kg N ha^{-1}. A progressive increase in P level through applied fertilizer also gradually increased the content and uptake of phosphorus by *Salicornia* biomass (spikes + seed). The highest uptake of phosphorus was recorded with the treatment P_2, giving highest yield of spikes which was higher by 22 and 41% over P_1 and P_0, respectively. However, the effect of phosphorus application on N and K

Table 2: Effect of nitrogen on yield and its attributes of *Salicornia brachiata* (Roxb.)

Nitrogen levels	Seed yield (kg ha^{-1})	Plant height (cm)	Plant canopy (cm)	No. of main branch	No. of spike/ branch	Spike length (cm)	No. of segment	Plant dry biomass (kg ha^{-1})	HI (%)
N0	491.2	31.0	111.8	32.9	482.1	8.4	5.10	4552	16.80
N1	773.2	30.9	131.4	33.3	552.4	9.6	5.60	5880	21.40
N2	918.2	30.1	129.1	34.5	377.7	13.5	7.70	6912	32.50
SEm	127.45	0.65	4.22	1.47	50.25	1.06	0.55	468	3.18
CD at 5%	311.93	NS	14.56	NS	NS	3.66	1.91	1664	10.99

Table 3: Effect of phosphorus on yield and yield attributes of *Salicornia brachiata* (Roxb.)

Phosphorus levels	Seed yield (kg ha^{-1})	Plant dry Biomass (kg ha^{-1})	Plant height (cm)	Plant canopy (cm)	No. of main branch	No. of spike/ branch	Spike length (cm)	No. of segment	HI (%)
P0	571.6	5192	30.10	123.9	33.2	424.2	9.80	5.7	24.9
P1	609.0	6016	31.70	125.9	33.3	423.8	11.00	5.9	28.9
P2	846.2	7144	30.20	122.3	34.1	564.2	11.40	8.2	41.8
S. Em.	88.10	759.2	0.51	4.51	2.91	52.06	0.56	0.49	13.1
CD at 5%	215.6	NS	NS	NS	NS	NS	NS	1.72	NS

Table 4: Interaction effect of nitrogen and phosphorus on seed yield (kg ha^{-1}) of *Salicornia*

Nitrogen/Phosphorus	P_0	P_1	P_2	Mean
N0	291.8	342.4	423.1	352.4
N1	505.8	532.2	451.1	496.4
N2	470.1	574.6	598.0	547.6
Mean	422.6	483.1	490.7	---
Interaction CD	183.5			

Table 5: Effect of nitrogen and phosphorus on their content and uptake in *Salicornia* plant biomass (Matured spike)

	Nutrient content (%)			Uptake of nutrient (kg ha^{-1})		
Nitrogen (kg ha^{-1})	N	P	K	N	P	K
0	0.433	0.180	0.587	16.674	8.109	22.66
75	0.680	0.183	0.777	40.963	10.680	37.59
100	0.987	0.213	0.630	68.274	12.510	43.45
CD at 5%	0.3523	0.0271	0.180	32.74	NS	12.46
Phosphorus (kg ha^{-1})						
0	0.600	0.157	0.627	32.702	7.915	32.022
50	0.697	0.193	0.653	39.835	9.664	34.484
75	0.803	0.227	0.713	53.374	13.721	37.204
CD at 5%	NS	0.0271	NS	NS	4.054	NS

content and uptake was found non significant (Table 5). These findings are against the normal trend prevailing in arable soils where N and K is found increased with the application of P (Rajput *et al*., 1991; Sharma and Namdeo, 1992). Application of N also caused a considerable and significant increase in content of P but remained non significant for the uptake. Thus it is concluded that for achieving higher seed and biomass production of *Salicornia* spikes, higher doses of N and P should give to this species.

Effect of Plant Density

Plant density did not affect positively the height of *Salicornia brachiata* plant. This is due to high succulent nature of the species, preferring salty water. But plants did grow significantly wider under T_3 over T_0 and T_2. Plant density in control (T_0) recorded the least canopy width of plant due to the limited availability of moisture, nutrients, space and light for better growth. Higher plant density resulted in severe competition for space, light etc. As a result of low plant density, there was significant increase in number of secondary branches per plant and number of spikes per secondary branches in T_1 followed closely by T_3, both being at par. Chandel *et al*. (1994) and Halvankar *et al*. (1999) also reported higher values for the branches per plant and pods per plant at lower planting density in an oil-bearing crop like soybean. The T_3 recorded the highest number of spike segments and segment length (Table 6b) and Plant density under T_3 had significantly more accumulation of shoot weight per plant than rest of densities. It also produced higher accumulation of root weight per plant. T_3 also produced significantly higher dry biomass (7727 kg ha^{-1}) over control and spike weight per plant (56.27 g/plant) than rest of the treatments (Table 6a).

Table 6a: Effect of plant density on biomass and yield attributing characters of *Salicornia*

Parameters	Dry Bio-mass (kg ha^{-1})	Main root length (cm)	Lateral root length (cm)	No. of lateral root	Root weight (gm)	Shoot weight (gm)	Spike weight (g/plant)	Harvest index (%)
T_0	5799	15.53	35.53	12	3.34	32.7	59.99	8.31
T_1	5822	11.47	39.17	16.93	2.13	37.04	58.84	12.99
T_2	5878	7.13	43.8	10.9	3.62	27.45	54.13	13.95
T_3	7727	6.97	44.27	17.27	7.77	56.27	98.12	13.42
CD at 5%	1476	4.17	NS	NS	NS	19.38	31.81	NS

Table 6b: Effect of plant density on yield and yield attributing characters of *Salicornia*

Parameters	Seed yield (kg ha^{-1})	Plant height (cm)	Plant canopy (cm)	No. of second Bran	No. of spikes/ branch	No of Segment per spike	Spike length (cm)
T_0	257.9	33.13	104.87	56.40	16.88	46.33	14.33
T_1	561.1	33.2	136.60	84.33	42.27	26.80	8.00
T_2	575.3	33.27	122.67	49.80	32.87	70.07	26.2
T_3	639.5	34.87	145.67	64.73	29.53	52.40	16.4
CD at 5%	207.55	NS	24.94	23.32	16.38	NS	NS

Table 7: Morphology of *Salicornia* at different growth phases

Observation	Plant height (cm) 2002-03	Plant height (cm) 2003-2004	Plant canopy (cm) 2002-03	Plant canopy (cm) 2003-2004
Vegetative stage (90 DAS in November)	32.73	29.13	97.47	117.51
Flowering stage (120 DAS in December)	39.67	34.51	119.25	159.55
	(21.2%)	(18.46%)	(22.34%)	(35.7%)
Seed setting stage (165 DAS in January)	37.10	32.96	130.71	167.31
	(6.5%)	(12.9%)	(9.6%)	(3.04%)
CD at 5%	4.10	3.61	19.11	26.14

The seed yield was found significantly influenced by the plant population. The plant density if resorted to T_3, produce significantly highest yield (639.5 kg ha^{-1}) over control (T_0) but remained at par with T_1 and T_2 (Table 6b). This is due to better geometric arrangement resulting in more photosynthesis and better absorption of soil moisture and nutrients and consequently resulting into high seed productivity in the species. The character length of spike is significantly decreased with increase in spacing, which may be due to the fact that root has to go deeper for getting nutrient and moisture due to heavy competition whereas, lateral root length is increased with increase in available spacing, due to better scope of available food, though found not significant. Better root development at lower plant densities was due to less competition and more availability of moisture and nutrients. Similar results have also been reported in *Arachis hypogea* L. (Bhan and Mishra, 1971; Chauhan and Sobaran, 1991).

Amongst the plant density, T_1 recorded very low values for yield attributes like seed yield per plant, spike weight per plant, plant biomass, number of spikes per branches and plant canopy. These have resulted in low biomass and seed yield output. This neither gets compensated with higher number of plants. The harvest index (%) remained highest for T_3 (13.66) followed by T_2 and T_1.

Growth Pattern Observation in Salicornia

First observations were recorded after 90 DAS in the month of November considering as vegetative phase when the *Salicornia* foliage were showed a dark-green colour. During this stage, plant height was observed 32.73 and 29.13 cm whereas, plant canopy remained 97.17 and 117.5 cm for the year of 2001-02 and 2002-03, respectively.

This difference in height and canopy may be largely due to delay in transplanting of the seedling. Second observation taken during the month of December i.e., after 120 DAS, when flowering starts, plant height was found significantly higher over the previous observation with an increase of 21.2 and 18.4% for the year 2001-02 and 2002-03, while canopy growth trend also indicated and showed it significantly higher in both the year with an increase of 22.3 and 35.7% in the respective yearsand. This suggests that though the flowering stage initiate for the species during the month of December, the vegetative growth remain continued in the both the years. Third observations recorded and taken were at seed filling stage which was during the month of January, after 165 DAS. During this stage plants colour changes from dark green to brownish red. At this phase, plants height is found decreasing by 6.5 and 12.9% for the previous observation for the year of 2002-03 and 2003-04, respectively. This is attributed due to succulent nature of species so lowering down of plant because of the weight of spikes due to seed filling in its cavity. Plant canopy however still had positive growth trend but of low magnitude i.e., 9.6 and 3.04% measured over the growth observed during December for the both the years (Table 7).

Conclusions

The findings here indicates a potential benefit of *Salicornia brachiata* if resorted and integrated to crop production system in saline ingressed soils for enhancement of scope of sustainable marine ecosystem and as remedial measure of coastal saline agriculture of world inclusive of salt affected waste lands.

Optimum plant density of 278 plants 10 m^{-2} and 100 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1} have had good impact on improvements of vegetable biomass and oil of *Salicornia brachiata*. This findings will help farming community and producers a new alternative cropping system which has high industrialization potential for its valued Nutritional salt, Linoleic rich oil and plant bioactives' assets obtainable from saline wastelands.

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