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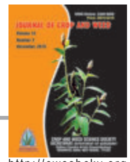

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Effect of sources of irrigation and nutrient doses on soil fertility, salinity and aggregation in *Salicornia brachiata* Roxb. at Navsari, Gujarat

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ABSTRACT

An experiment was carried out at Coastal Soil Salinity Research Station, Dhanti–Umbharat, Navsari, Gujarat to study the effect of source of irrigation (S_1-sea water, S_2-aquaculture effluent) and fertilizer dose (F_1-No fertilizer, F_2- 125:37.5:25 kg ha^{-1} NPK, F_3- 250:75:50 kg ha^{-1}NPK) on soil fertility, salinity and aggregation in Salicornia brachiata Roxb. Results revealed aquaculture effluent irrigation and 100% recommended fertilizer dose increased SOC content and soil CEC by 38.6 and 20.0, and 17.1 and 2.14% at 0-15 and 15-30 cm soil depth, recpectively. The soil available nutrients increased, soil salinity parameters decreased and soil aggregation improved with aquaculture effluent irrigation and 100% recommended fertilizer dose, irrespective of soil depth. Along the depth, SOC, cationic nutrient, CEC, SAR, ESP and aggregate (>1mm) decreased, while, anionic nutrient and pH increased. Thus, the application of aquaculture effluent irrigation water and 100% recommended fertilizer dose were suggested for Salicornia brachiata Roxb. in Navsari, Gujarat.

***Keywords* :** Aquaculture effluent, recommended fertilizer dose, *Salicornia brachiata*, soil aggregation, soil fertility, soil salinity

Sea water forms a strong base for the growing aquaculture industry but releases nutrient rich effluents into the surrounding environment (Karakassis *et al*., 2005; Ghaly, 2002; Wu, 1995; Goldberg and Forester, 1990). Such activities without management are predicted to deteriorate the soil properties in the long term. This drives the need to develop sustainable waste management option that shall efficiently use aquaculture effluent. Species that have greater biomass production together with the ability to withstand ambient soil salinity and sodicity and periodic inundation can efficiently reclaim soil (Ghaly, 2002). Thus, reuse of aquaculture effluent as irrigation for halophyte (*Salicornia* sp.) production appears to be a lucrative option (Brown *et al*., 1999).

The state of Gujarat shares longest coastline of 1600 km (out of 7516 km length) in India. The state is also accustomed to soil salinity related problems affecting socio-economic and agro-climatic condition where, salt intrusion causes saline fallow lands that are fastened by natural calamities coupled with human exploitation (Stanley, 2008). It is observed that *Salicornia* crop (*Salicornia rubra*) can achieve maximum and critical fresh and dry biomass yield with 200 mM NaCl solution (Khan *et al*., 2001). Halophytes like *Salicornia brachiata* Roxb. that are habitant of salt marsh are gaining popularity for saline soil reclamation ability. It has been reported that soil SAR was lowered in crops that have more Na concentration in the leaves (Hegedus *et al*., 2009). Also, aquaculture effluent positively increased SOC, total N and available P (Ojobor and Tobih, 2015) as a result of increase in microbial population density (Deshmukh *et al*., 2011). Aquaculture effluent increased soil pH as a result of increase in soil exchangeable bases (Ojobor and Tobih, 2015).However, addition of nutrient loaded waste water affects the soil microbial population in Vertisol due to reduction in pores space (Deshmukh *et al*., 2011).

Salicornia is also used as vegetable salt due to its high Na content in the spikes (about 9.12%) (Tasung *et al*., 2015). Based on nutritional condition studies it has been identified that *Salicornia brachiata* Roxb needs high quantity of nitrogen fertilizer (Rueda-Puente *et al.*, 2004). Similarly, *Salicornia brachiata* seed yield and plant biomass were increased upto 87% and 51% with 100 kg recommended dose of nitrogen (RDN) (Pandya *et al*., 2006) and fresh biomass yield was increased almost 70% with 125 kg RDN and 250 kg RDN (Tasung *et al*., 2015) in Gujarat condition. The soil properties like SOC, fertility and salinity were improved with addition of mineral fertilizer (Ojobor and Tobih, 2015;

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Dong *et al*., 2012). However, mineral fertilizers have adverse effect on soil properties (nutrient imbalance, soil acidity, etc). As soil is the base medium for crop production it is imperative to consider the long term effect of mineral fertilizer and aquaculture effluent on the soil properties and determine the optimum soil condition for *Salicornia* production under local conditions. Hence,this study was conducted with the aims of evaluating the effect of aquaculture effluent irrigation and RDF on soil fertility, salinity and aggregation in production of *Salicornia*.

Climate and soil

Dhanti-Umbharat, Navsari, Gujarat is situated at 20^0 83' N latitude and 72^0 50' E longitudes at an elevation of 2.5 meter above sea level on the western coastal belt of India. The agro-climatic condition is characterized by humid and warm monsoon with heavy rainfall (around 1500 mm), moderately cold winter and fairly hot and humid summer. The research station is located under hyperthermic temperature regime i.e., the mean annual soil temperature is above 22°C with an ustic moisture regime i.e. a regime between aridic and udic regime. Genesis of the Danti soil is Onjal-1 and Dandi series subgrouped as *Typic Halaquept* while Att series is *Fluventtic Halaquept*. The soil water holding capacity is good and medium to poor drainage with flat topography. The clay content ranges from 42 to 50 per cent pre-dominated with montmorillonite types of clay mineral. The initial soil parameters status is given in Table 1.

Experiment details

The field experiment was carried out based on split plot design with sources of irrigation water (S_1-sea water, S_2-aquaculture effluent) as main plot and different doses of fertilizer (F_1-No fertilizer, F_2- 125:37.5:25 kg ha^{-1}NPK, F_3- 250:75:50 kg ha^{-1} of NPK) as subplot plot in four replications during 2012. Irrigation with good quality water was applied at the initial stage for proper plant establishment and five irrigation treatments was supplied with seawater and aquaculture effluent (shrimp culture) in gross (4.5 x 3.0 m^2) and net (1.2 x 2.0 m^2) plots.

Soil sampling and analysis

Soil samples were collected at the start and end of the study to measure nutrient concentration, soil salinity and soil aggregation. Two samples [0-15cm (surface soil) and 15-30 cm (sub surface)] were collected from each of the experimental plots with 1.5-m soil auger. All samples were labeled and packed in polythene bag for laboratory analysis.

The soil pH was determined by potentiometric method (Jackson, 1973), EC by conductometric method (Jackson, 1973), cation exchange capacity (CEC) by Neutral normal ammonium acetate method (Jackson, 1973), soil organic carbon (SOC) by Walkley and Black (wet oxidation) (Jackson, 1967), soil available nitrogen (N) by 0.32 per cent alkaline $KMnO_4$ (Subbiah and Asija, 1956), soil available P_2O_5 by 0.5 M $NaHCO_3$ (pH 8.5) (Olsen *et al.,* 1954), soil available K_2O by Neutral N NH_4OAc (Jackson ,1967), soil available sulphur (S) by turbidometric (Williams and Steinbergs, 1959), soil available micronutrient by 0.005 M DTPA Atomic Absorption Spectrophotometric (Lindsay and Norvell, 1978) and soil aggregates by Yoder's wet sieving methods (Black, 1965). The soil sodium (Na^+) by flame photometer (Jackson, 1967) and soil exchangeable sodium percentage (ESP) and sodium absorption ratio (SAR) were calculated by the formulae given below.

ESP = [100 (-0.0126 + 0.01475 x SAR)] / [1 + (-0.0126 + 0.01475 x SAR)]

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$$

Statistical analysis

The means of the soil parameters were subjected to ANOVA by Panse and Sukhutme statistical method.

Impact of sources of irrigation and levels of fertilizer on SOC percentage and CEC along the depth

The SOC was ranged from 0.40 to 0.55% across source of irrigation. Aquaculture effluent irrigation significantly increased the SOC as compared to sea water irrigation by 38.6 and 20.1% at surface and sub surface soil, respectively (Fig. 1). This increase suggests more humus accumulation in soil from aquaculture effluent than seawater irrigation (Ojobor and Tobih, 2015). Among levels of fertilizer, mean SOC ranged from 0.41-0.55 % irrespective of soil depth. Among the levels of RDF, the SOC percentage increased from no fertilizer to 100% RDF by 2.14% and 17.1% at surface and sub-surface soil. The application of chemical fertilizer had higher SOC because of improvement in soil condition by promoting crop growth and return of more root residues into the soil (Guo *et al*., 2019; Dong *et al*., 2012; Hyvonen *et al*., 2008). Along the depth, 20.1% more SOC was accumulated in the surface soil compared to sub surface soil due to higher accumulation of plant litter in the top soil and prevention of SOC movement to lower soil depth.

The soil CEC was ranged from 39.3-49.0 and 41.0-43.4 me $100g^{-1}$ at surface and sub surface soil, irrespective of treatments (Fig. 2). Among the sources of irrigation, soil CEC was higher in aquaculture irrigation than sea water irrigation by 6.00 and 3.52 % at surface and subsurface soil. The soil CEC was increased with increase in fertilizer dose in no fertilizer

Table 1: Initial values of soil analysis at 0-15 and 15-30 cm of main plots

Soil parameter	Sea water (S_1)		Aquaculture effluent (S_2)	
	Soil depth (cm)		Soil depth (cm)	
	0-15	15-30	0-15	15-30
$pH_{(1:2.5)}$	8.31	8.42	8.14	8.32
$EC_{(1:2.5)}$ (dS m^{-1})	9.57	6.02	13.2	9.48
OC (%)	0.31	0.23	0.30	0.23
N (kg ha^{-1})	201	220	215	262
P_2O_5 (kg ha^{-1})	11.2	12.9	12.0	14.0
K_2O (kg ha^{-1})	2697	2101	3091	2114
S (kg ha^{-1})	39.3	43.6	45.8	47
CEC (me100g^{-1})	67.1	70.9	79.1	79.4
ESP	54.5	44.9	47.7	46.2
SAR	4.29	3.11	4.21	3.69
Fe (ppm)	3.18	3.11	3.73	2.89
Mn(ppm)	2.10	2.38	2.12	2.43
Zn (ppm)	0.32	0.43	0.34	0.4
Cu (ppm)	0.41	0.67	0.42	0.68

to 100% RDF by 17.2 and 2.14% at surface and sub-surface soil. The high soil CEC in aquaculture effluent can be associated with presence of higher SOC. A study claimed treated waste water and sea water had higher soil CEC (12.67 me 100 g^{-1}) than the portable tap water treatment (3.47 me 100 g^{-1}) due to higher organic loading (Ahmed and Al-Hajri, 2009). Along the depth the soil CEC was decreased by 3.62% which can be explained from lower SOC at lower depth.

Impact of sources of irrigation and levels of fertilizer on soil available macro- and micro- nutrients along the depth

The range of soil available N, P, K and S was 236-534 and 456-973, 14.3-26.1 and 16.4-27.8, 3494-5642 and 2399-28.78 kg ha^{-1} and 21.0-24.4 and 28.2-29.5 ppm at surface and sub surface soil layers irrespective of treatments (Table 2). The range of soil available Fe, Mn, Zn and Cu was 4.09-7.59 and 3.50-5.29, 2.29-5.03 and 2.66-3.82, 0.54-0.78 and 0.43-0.72, and, 0.67-1.27, and 1.13-2.26 ppm at surface and sub surface soil layers irrespective of treatments (Table 3). Aquaculture effluent irrigation increased the soil available N, P, K, S, Fe, Mn, Zn and Cu by 10.0-41.7 and 3.57-47.2 % as compared to sea water irrigation at surface and sub surface soil, respectively. Similarly, addition of 100% RDF increased the soil available N, P, K, S, Fe, Mn, Zn and Cu by 7.7-37.6 and 3.7-44.1% at surface and sub surface soil. Soil available nutrients (N, P, K, S, Fe, Mn, Zn and Cu) were increased in aquaculture effluent irrigation and 100% RDF due to higher SOC accumulation with aquaculture effluent irrigation, nutrient loads from aquaculture effluent (Jegatheesan *et al*., 2011) and improvement in soil conditions (Guo *et al*., 2019). Along the depth, cationic soil available nutrients (K^+, Fe^{2+}, Mn^{2+}, Zn^{2+}) were higher and anionic soil available nutrients (NO_2^-, $H_3PO_4^-$ and SO_4^{2-}) were lower in surface soil as compared to subsurface soil irrespective of treatments. This suggests higher complex formation of cationic nutrients with SOC in surface soil and leaching of anionic nutrients to lower depth.

Impact of sources of irrigation and levels of fertilizer on salinity parameters ($pH_{(1:2.5)}$, $EC_{(1:2.5)}$, ESP and SAR) along the depth

The soil pH was ranged from 8.41 to 8.45 and 8.44 to 8.48 at surface and sub surface soil irrespective of treatments (Table 4). Aquaculture effluent irrigation increased the soil pH by 0.11 and 0.35 % at surface and sub surface soil compared to sea water irrigation attributing to presence of higher cations in aquaculture effluent. Soil pH was decreased and increased with the application of RDF at surface and increased at sub surface soil by 0.35%. This decrease in soil pH at surface soil is due to acidifying effect of mineral fertilizer. Soil pH increased along the depth by 0.27% due to lower SOC at sub surface soil.

At surface and sub-surface soil, range of soil $EC_{(1:2.5)}$ was 8.94-9.88 and 7.68-8.67 dSm^{-1}, irrespective of sources of irrigation and levels of fertilizer (Table 5). Among source of irrigation, soil $EC_{(1:2.5)}$ was higher in sea water than aquaculture effluent irrigation at both the soil layers. Among levels of fertilizer at both soil layers, soil $EC_{(1:2.5)}$ was decreased with increase in RDF at soil depth. The reduction in soil $EC_{(1:2.5)}$ with aquaculture effluent and higher RDF may be due to higher absorption of salt by *Salicornia* for its metabolism. The irrigation of halophyte tamarisk

Table 2: Change in soil available macronutrients after application of seawater and aquaculture effluent irrigation and levels of RDF along 0-30 cm soil depth at harvest of *Salicornia brachiata* Roxb.

	soil available N (kg ha^{-1})			soil available P_2O_5 (kg ha^{-1})			soil available K_2O (kg ha^{-1})			soil available S (mg kg^{-1})		
Soil depth (0- 15 cm)												
	Irrigation Source		**Mean**	**Irrigation Source**		**Mean**	**Irrigation Source**		**Mean**	**Irrigation Source**		**Mean**
RDF	**S_1**	**S_2**	**(F)**	**S_1**	**S_2**	**F**	**S_1**	**S_2**	**F**	**S_1**	**S_2**	**F**
F_1	236	368	302	14.3	18.7	17.7	3494	4443	3969	21.0	23.1	22.0
F_2	372	481	427	18.7	26.1	22.4	3864	4983	4424	21.7	24.1	22.9
F_3	425	544	484	22.9	22.4	26.9	4174	5642	4908	23.4	24.4	24.3
Mean (S)	344	465		18.6	22.4		3844	5023		22.0	24.2	
	S	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	36.5	12.2	NS	0.47	SF	NS	198	57.0	80.6	0.62	0.27	NS
Soil depth (15-30 cm)												
RDF	S_1	S_2	(F)	S_1	S_2	(F)	S_1	S_2	(F)	S_1	S_2	(F)
F_1	456	606	531	16.6	23.0	19.8	2131	2668	2399	27.4	28.4	27.9
F_2	869	929	899	18.7	25.2	21.9	2149	2861	2505	28.2	29.0	28.6
F_3	927	973	950	23.1	27.8	25.4	2644	3113	2878	28.5	29.5	29.0
Mean (S)	751	836		19.4	25.3		2308	2881		28.0	29.0	
	S	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	20.1	32.8	46.4	1.03	0.69	0.97	227	245	NS	0.35	0.15	NS

Note: The abbreviations are S_1- seawater, S_2 – aquaculture effluent, F_1 – No fertilizer, F_2 – 50% RDF (125: 37.5: 25 kg ha^{-1} NPK, F_3 – 100% RDF (250: 75: 50 kg ha^{-1} NPK), LSD - Least Significant Difference

Table 3: Change in soil available micronutrients content after application of seawater and aquaculture effluent irrigation and levels of RDF along 0-30 cm soil depth at harvest of *Salicornia brachiata* Roxb

	soil available Fe (mg kg^{-1})			soil available Mn (mg kg^{-1})			soil available Zn (mg kg^{-1})			soil available Cu (mg kg^{-1})		
Soil depth (0- 15 cm)												
	Irrigation Source		**Mean**	**Irrigation Source**		**Mean**	**Irrigation Source**		**Mean**	**Irrigation Source**		**Mean**
RDF	**S_1**	**S_2**	**(F)**	**S_1**	**S_2**	**F**	**S_1**	**S_2**	**F**	**S_1**	**S_2**	**F**
F_1	4.09	5.38	4.73	2.29	3.41	2.85	0.54	0.64	0.59	0.67	0.92	0.79
F_2	5.29	6.47	5.88	3.47	4.53	4.00	0.59	0.74	0.66	0.82	1.18	1.00
F_3	6.68	7.59	7.13	3.80	5.03	4.41	0.69	0.78	0.74	0.90	1.27	1.08
Mean (S)	5.35	6.48		3.18	4.32		0.61	0.72		0.79	1.12	
	S	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	0.15	0.17	NS	0.77	0.07		0.04	0.02	0.03	0.02	0.02	0.02
Soil depth (15-30 cm)												
RDF	S_1	S_2	(F)	S_1	S_2	(F)	S_1	S_2	(F)	S_1	S_2	(F)
F_1	3.50	3.57	3.53	2.66	3.63	3.14	0.43	0.56	0.49	1.13	1.75	1.44
F_2	4.38	4.78	4.58	2.79	3.82	3.30	0.52	0.66	0.59	1.53	2.26	1.89
F_3	4.75	5.29	5.02	2.94	3.90	3.42	0.59	0.72	0.66	1.66	2.37	2.01
Mean (S)	4.21	4.54		2.80	3.78		0.51	0.65		1.44	2.12	
	S	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	0.28	0.22	NS	0.11	0.03	NS	0.02	0.02	NS	0.06	0.05	NS

Note: The abbreviations are S_1- seawater, S_2 – aquaculture effluent, F_1 – No fertilizer, F_2 – 50% RDF (125: 37.5: 25 kg ha^{-1} NPK, F_3 – 100% RDF (250: 75: 50 kg ha^{-1} NPK), LSD - Least Significant Difference

Table 4: Change in soil salinity parameters after application of seawater and aquaculture effluent irrigation and levels of RDF along 0-30 cm soil depth at harvest of *Salicornia brachiata* Roxb

	soil $pH_{(1:2.5)}$			Soil $EC_{(1:2.5)}$ ($dS\ m^{-1}$)			Soil ESP			soil SAR		
Soil depth (0- 15 cm)												
	Irrigation source		**Mean**	**Irrigation source**		**Mean**	**Irrigation Source**		**Mean**	**Irrigation Source**		**Mean**
RDF	S_1	S_2	(F)	S_1	S_2	F	S_1	S_2	F	S_1	S_2	F
F_1	8.44	8.45	8.45	9.88	8.94	9.78	54.0	48.6	51.3	5.25	4.60	4.92
F_2	8.43	8.45	8.44	9.69	9.21	9.07	53.5	47.1	50.3	5.48	4.64	5.06
F_3	8.41	8.42	8.41	9.78	9.07	8.32	52.5	45.9	49.2	5.51	4.70	5.10
Mean (S)	8.43	8.44		9.78	9.07		53.3	47.2		5.41	4.65	
	S	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	0.010	0.01	NS	0.112	0.911	NS	0.957	0.713	NS	0.247	0.103	NS
Soil depth (15-30 cm)												
RDF	S_1	S_2	(F)	S_1	S_2	(F)	S_1	S_2	(F)	S_1	S_2	(F)
F_1	8.44	8.45	8.46	8.63	8.40	8.52	55.6	49.8	52.7	5.79	4.99	5.39
F_2	8.46	8.48	8.50	8.67	7.96	8.32	48.9	43.2	46.1	4.69	4.03	4.36
F_3	8.45	8.46	8.48	8.17	7.68	7.92	44.6	39.2	41.9	4.08	3.56	3.82
Mean (S)	8.45	8.48		8.49	8.01		49.7	44.1		4.85	4.19	
	S	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	0.028	0.012	NS	8.49	8.01	NS	1.935	0.939	NS	0.359	0.161	NS

Note: The abbreviations are S_1- seawater, S_2 – aquaculture effluent, F_1 – No fertilizer, F_2 – 50% RDF (125: 37.5: 25 kg ha^{-1} NPK, F_3 – 100% RDF (250: 75: 50 kg ha^{-1} NPK),EC – Electrical conductivity, ESP –Exchangeable sodium percentage, SAR – Sodium absorption ratio, LSD - Least Significant Difference.

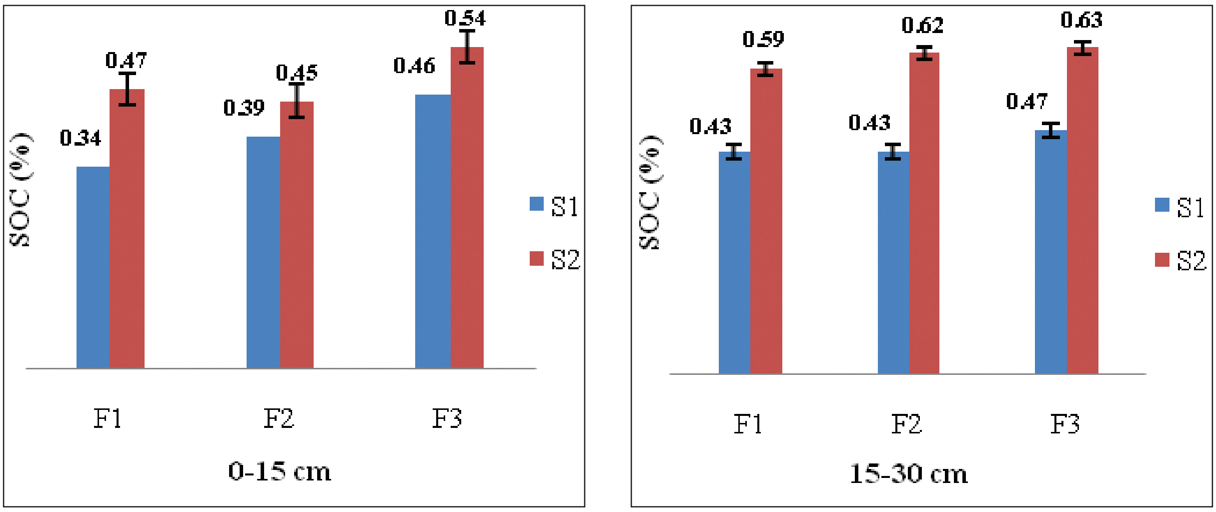

Fig. 1: Change in soil organic carbon (percentage) after application of seawater (S_1) and aquaculture effluent (S_2) irrigation and three levels of RDF (F_1, F_2, F_3) in 0-15 and 15-30 cm soil depth at harvest of *Salicornia brachiata* Roxb.

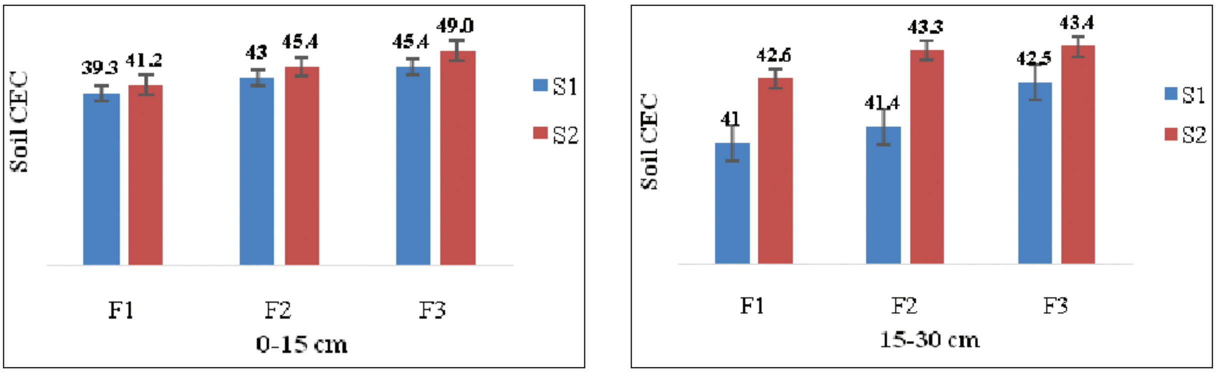

Fig. 2: Change in soil CEC (me 100g^{-1})after application of seawater (S_1) and aquaculture effluent (S_2) irrigation and three levels of RDF (F_1, F_2, F_3) in 0-15 and 15-30 cm soil depth at harvest of *Salicornia brachiata* Roxb.

reduced the salinity (822±148 mg L^{-1}) of effluent water from African catfish farm (*Tamarix tetranda* Pall.) and "energy willow" (*Salix viminalis* L.) (Hegedus *et al.*, 2009). Along the depth, soil EC was lower by 9.79% at subsurface soil which suggests either slowed movement of soluble salt along the depth or higher absorption of salt by *Salicornia* for its metabolism.

Soil ESP and SAR were ranged from 45.9-54.0 and 39.2-55.6, and, 4.60-5.51 and 3.56-5.79 at surface and sub surface soil irrespective of treatments (Table 5). Soil ESP and SAR were higher in sea water compared to aquaculture effluent irrigation. Seawater irrigation increased soil ESP and SAR by 11.5 and 11.3 %, and 14.1 and 7.30 % at surface and sub surface soil as compared to aquaculture irrigation. Across levels of fertilizer, soil ESP and SAR were decreased with the increase in fertilizer level ($F_1 > F_2 > F_3$) at surface and sub surface soil, respectively. Application of 100% RDF reduced soil ESP by 4.29 and 25.8 % at surface and sub surface soil, respectively as compared to no fertilizer. Similarly, application of 100% RDF reduced the soil SAR by 3.65 and 41.0 % at surface and sub-surface soil, respectively. Along the depth, soil ESP and SAR were decreased along the depth.

The soil pH, EC, ESP and SAR indicate the soil is saline sodic soil. The aquaculture effluent irrigation and application of 100% RDF decreased the soil ESP and SAR mostly because of higher SOC accumulation and soil CEC as compared to seawater irrigation and no fertilizer (Fig. 1 and 2.).

Impact of sources of irrigation and levels of fertilizer on soil aggregate (>1mm) along the depth

The range of soil aggregate (>1mm) was 61.8-69.7 and 58.3-67.4 % at surface and sub surface layers, respectively (Table 5). Change in mean soil >1mm water

Table 5: Change in per cent soil aggregates (>1mm) after application of seawater and aquaculture effluent irrigation and levels of RDF along 0-30 cm soil depth at harvest of *Salicornia brachiata* Roxb.

	Soil depth					
	0-15 cm			15-30 cm		
RDF	S_1	S_2	**Mean (F)**	S_1	S_2	**Mean (F)**
F_1	61.75	67.90	64.83	58.28	66.80	62.54
F_2	62.16	68.63	69.39	58.85	67.06	62.96
F_3	62.63	69.65	66.14	59.18	67.44	63.31
Mean (S)	62.18	68.73		58.77	67.10	
	S	**F**	**S×F**	**S**	**F**	**S×F**
LSD (0.05)	0.80	0.13	0.18	6.04	0.23	NS

Note: The abbreviations are S_1- seawater, S_2 – aquaculture effluent, F_1 – No fertilizer, F_2 – 50% RDF (125: 37.5: 25 kg ha^{-1} NPK, F_3 – 100% RDF (250: 75: 50 kg ha^{-1} NPK),LSD – Leas Significan Difference

stable aggregates (WSA) followed an order $S_2 > S_1$ and $F_3 > F_2 > F_1$ across sources of irrigation and levels of fertilizer at both soil depths. Applying irrigation water, with high salinity increased the WSA (El-Maghraby, 1997; Fireman and Bodman, 1940). But, high Na^+ caused a strongly alkaline reaction and aggregate disintegration (Szombathova *et al*., 2008). Saad *et al*., (2011) reported increased salinity in irrigation water using NaCl and $CaCl_2$ with EC (16 dS m^{-1}) that led to increase in soil water stable aggregates > 0.25 mm and mean weight diameter (MWD). Therefore, in the current study, irrigation of *Salicornia* with aquaculture effluent irrigation increased soil aggregate (>1mm WSA) by 10.5 and 14.1 % at surface and sub surface layers, respectively as compared to seawater irrigation. Also, increase in levels of fertilizer increased soil aggregate (>1mm) by 2.02% and 1.23% at surface and sub surface layers, respectively due to improvement in soil physical properties (Dong *et al*., 2012; Hyvonen *et al*., 2008). Soil aggregation (>1mm) was lower by 4.00% at sub surface soil (15-30 cm). The decrease in soil SAR and ESP and increase in SOC content must have contributed to the higher aggregation in aquaculture effluent irrigation and 100% RDF application.

CONCLUSION

In this experiment, we can conclude application of aquaculture effluent irrigation and 100% RDF application increased SOC and soil CEC. The soil available macro and micro nutrients were higher in aquaculture effluent irrigation and 100% RDF application due to higher SOC accumulation at both the soil depths. The anionic nutrients availability was increased and cationic nutrient availability was decreased at subsurface and surface soil. Application of 100% RDF reduced soil pHreduction due to acidifying effect of mineral fertilizer. The lower soil SAR and ESP in aquaculture effluent and 100% RDF application attributing to lower salt and Na^+ concentration along the depth improved the soil aggregation (>1mm). Thus, it can be concluded that aquaculture effluent and 100% RDF are suggesed for beer production of *Salicornia brachiata* Roxb. in Navsari area, Gujarat, India.

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