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Growth, productivity and nutritional status of *Salicornia brachiata* Roxb. cultivated in saline soils supplemented with organic manures under sea water irrigation

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ABSTRACT

Halophytic crops are being explored for their nutritional, culinary, oilseed, forage/ feed crop, medicinal, and wastewater treatment potential. Along the Palk Bay region, a short term field experiment was conducted at coastal inlands of Kattumavadi village of Puthukottai district, Tamilnadu during the monsoon season of 2017 to evaluate the cultivation potential of *Salicornia brachiata* Roxb. in coastal sandy loam soil supplemented with different rates of farmyard manure (FYM) and halophytic compost (HC) irrigated with sea water. Observations recorded in the present study clearly indicated that the supplemental fertilizers can play a vital role in restoration of soil fertility, particularly in terms of available nitrogen and organic carbon in saline soils. HC treated plants showed increased biomass production (3240 Kg ha⁻¹) at 60 DAP compared to control and other treatments. The application of FYM @ 2 ton ha⁻¹ and HC @ 1 ton ha⁻¹ significantly enhanced dry matter production and the proximate analysis exhibited less variation in total phenols and ascorbic acid with the increase in the rates of manure applications.

KEYWORDS: *Salicornia brachiata*, halophytic compost, farmyard manure, biomass, sea water irrigation

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INTRODUCTION

World's food production will need to increase by up to 70% by 2050 as the world's population will reach 9.1 billion, 34 percent higher than today. The developing countries are in urge of developing new management practices to increase the productivity per unit land. Bio-saline agriculture is one of the recent, cost effective options for farming where land and water is not suitable for the conventional agriculture. The benefits of developing saline agriculture enable food, fodder, and biofuel production from degraded lands using low quality water resources (Panta *et al.*, 2014). Saline agriculture might become a viable strategy of future farming to deal with the growing food and biofuel demands of an increasing global population (Mala *et al.*, 2010). Halophytes are potential cash crops in saline agriculture, where they may be used for food, fibre and industrial purposes. Many halophytes have been evaluated for their potential use as crop plants (Flowers *et al.*, 2010), for the re-vegetation and remediation of salt and industrially polluted areas, as floricultural crops (Cassaniti *et al.*, 2013) and as biofilters for aquaculture effluents (Buhmann *et al.*,

2015). Recently, interest in certain 'functional foods,' which are endowed with exceptional nutritive values, is increasing (Giudice *et al.*, 2010). The new potential halophyte crops, cultivated as cash crops using saline water, meet those special nutritional demands.

Salicornia has been listed as one of the most salt-tolerant species among 1560 halophytes and has been shown to maintain normal growth even when soil NaCl concentration exceeds 1.3 M, two times greater than full-strength seawater salinity (Ventura *et al.*, 2011). Some studies indicate that *Salicornia* inhabits the broadest range of salinity and has very little phenotypic response to salinity gradient (Singh *et al.*, 2018). However, skepticism about their feasibility for use as alternative crop or forage species still remains. Since earlier biosaline agriculture trials experienced indirect influences of soil parameters such as pH and elemental deficiency, the growing protocols need to be adapted to the existing cultivation conditions, taking not only salt tolerance into account (Ventura *et al.*, 2013). Several organic materials have been researched in the aspect of improving soil physical properties (Lordan *et al.*, 2013), but, limited literature

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is available on the combination of organic manure and sea water irrigation for crop productivity in the soils of coastal inlands. The objective of this study was to determine the cropping potential of *Salicornia brachiata* Roxb., a halophytic leafy vegetable in the coastal inlands subjected to manure supplementation and sea water irrigation. No study in the literature was found on the salinity-fertility interaction of the halophytic species, so this study was initiated in order to facilitate and formulate a feasible reclamation process for the saline barren land along the coast of Palk Bay region.

MATERIAL AND METHODS

Experimental Design

The coastal village Kattumovadi (Lat. 10°4'N; Long. 79°12'E) of Puthukottai district along the Indian Palk Bay region has been selected for the current field studies. The potentiality of the site was identified based on the tidal wave patterns, mudflats with desirable tidal inundation patterns, accessibility, vegetation, tidal coverage, coarse fractions and debris, area available for planting etc. The field experiment was conducted at the barren coastal inland near seashore (≤ 1000 m) in randomized complete block design with three replicates, where sea water salinity distributed in the main plots, while farmyard manure (FYM) and halophytic compost (HC) treatments were randomly arranged in the sub-plots. The soil of experimental field was sandy loam in texture with low available N, P and K. The treatments used in this experiment were: T0: Control (no manure); T1: HC @ 0.5 ton ha⁻¹; T2: HC @ 1 ton ha⁻¹; T3: HC @ 2 ton ha⁻¹; T4: FYM @ 1 ton ha⁻¹; T5: FYM @ 2 ton ha⁻¹ and T6: FYM @ 5 ton ha⁻¹. For each treatment, three replicates of 6 x 4 ft size plots were earmarked with raised bunds all around to minimize the movement of water where each plot consists of 5 rows at uniform distance in between them.

Farmyard manure (FYM) was collected from the local dairy farm, air dried under the shade and large pieces were crushed. Halophytic compost (HC) used in this experiment was prepared using vegetative parts of *Clerodendron inerme* L., *Ipomoea pes-caprae* (L.), rice straw, animal wastes with a fungal decomposer *Pleurotus sajor-caju* (Fr.) Singer (Kalaiarasi & Arumugam, 2014). Both HC and FYM were added in single dose by incorporating into the soil to a depth of 10–30 cm, two weeks before planting. The healthy uniform (8–10 cm) seedlings of *Salicornia brachiata* Roxb. were collected from their natural field condition along the Palk Bay coastal zone and replanted in the experimental plots in rows where plant to plant distance was maintained at 15–20 cm. The plots were irrigated with seawater and the required amount of water was determined based on the soil moisture content of each treatment. The physico-chemical characters of halophytic compost, farmyard manure, experimental field soil and seawater used for irrigation were given in the Table 1.

Growth Attributes

Plant growth was measured at 30 and 60 DAP in terms of plant height, number of leafy shoots per plant, number of branches,

biomass, percent tissue water content (TWC%) and succulence index (Ls) (Slama *et al.*, 2008).

Proximate Compounds

Fully expanded leafy shoots were harvested and used for the biochemical analysis as per standard methods. Chlorophyll content was determined as described by Arnon (1949). Protein (Lowry *et al.*, 1951) and proline (Bates *et al.*, 1973) were also estimated as per standard procedures. Total ash content was estimated by furnaces incineration gravimetric method described by James (1995) and AOAC (1990). The membrane stability index (MSI) was determined as described by Premchandra *et al.* (1990) by measuring the electrical conductivity.

Total Phenol Content

Total phenolic contents were determined by the Folin Ciocalteu method proposed by Lin and Tang (Lin & Tang, 2007) 0.1 mL of the supernatant it was mixed with 2.8 mL of deionized water, 2.0 mL of 2% sodium carbonate (Na₂CO₃), and 0.1 mL of FolinCiocalteu reagents. After incubation at room temperature for 30 min, the absorbance of the reaction mixture was measured at 750 nm on a UV-visible spectrophotometer. The total phenol content was expressed as milligram gallic acid equivalents (GAE) 100 g⁻¹ fresh weight.

Ascorbic Acid

Leafy shoots of *S. brachiata* was extracted with oxalic acid at 0.4% in a ratio of 1:10 w/v and put in a dark room for 20 min before its centrifugation at 660 rpm. Later, 1 mL of the supernatant was mixed with sodium acetate buffer solution and a 2, 6-dichlorophenol indophenol solution. The absorbance of the solution was measured at 520 nm and the ascorbic acid content was calculated on the basis of an adjusted calibration curve of L-ascorbic acid standard, reported as ascorbic acid mg 100 g⁻¹ fresh weight (Durust *et al.*, 1997).

Nutrient Status and Food Value

The available sodium and potassium was estimated using the flame photometer method (Stanford & English, 1949). The available chloride content was estimated with the Mohr's titration method (Jackson, 1967) and other mineral nutrients were determined by Inductively Coupled Plasma Atomic Absorption Spectrometry (Optima 2000DV, PerkinElmer, USA). Carbohydrate, crude fibre was determined by the method of James (1995), crude fat was determined by solvent extraction gravimetric method described by Kirk and Sawyer (1980). The nutritional value of *Salicornia* was calculated as per the formula used by Nile and Khobragade (2009).

RESULTS AND DISCUSSION

Environmental Factors

Cultivating halophytes irrigated with saline water, has long and recurrently been considered an alternative farming method

Table 1: Physicochemical parameters of the experimental soil (ES), farmyard manure (FYM), halophytic compost (HC) and sea water (SW - mg L⁻¹)

Parameters	SW	ES	HC	FYM
pH	7.83±0.04	8.12±0.09	7.97±0.13	7.21±0.11
Temperature °C	30.6±0.31	36.4±0.28	33.6±0.18	34.6±0.27
EC (dS m ⁻¹)	46.8±0.37	11.52±0.23	8.08±0.09	1.69±0.13
OM %	0.73±0.03	2.06±0.04	42.87±0.11	19.4±0.21
OC%	0.32±0.01	1.34±0.05	31.67±0.19	14.8±0.12
N (mg g ⁻¹)	0.451±0.01	1.06±0.02	2.44±0.04	2.09±0.09
P (mg g ⁻¹)	0.208±0.03	0.221±0.01	0.334±0.03	0.312±0.03
K (mg g ⁻¹)	0.389±0.01	0.375±0.02	0.746±0.07	0.546±0.04
Na (mg g ⁻¹)	20.33±0.28	18.91±0.20	6.43±0.13	1.83±0.10
Ca (mg g ⁻¹)	0.423±0.04	0.575±0.01	0.695±0.03	0.672±0.05
Mg (mg g ⁻¹)	0.508±0.02	0.578±0.01	0.678±0.06	0.702±0.04
Cl (mg g ⁻¹)	22.12±0.27	20.64±0.38	8.23±0.12	2.04±0.08
Fe (ppm)	0.056±0.01	0.067±0.01	0.126±0.03	0.131±0.02
Zn (ppm)	0.018±0.01	0.024±0.01	0.091±0.03	0.089±0.01
Cu (ppm)	0.027±0.01	0.041±0.01	0.037±0.03	0.044±0.02

Values are mean±SE

that does not need freshwater and makes use of marginal land like coastal desert areas (Ventura *et al.*, 2015) Plant response to salinity varies appreciably with many environmental factors (e.g., soil fertility, soil physical conditions, irrigation methods and climate) and plant factors (e.g., growth stages, variety and rootstock). The environmental factors prevailed in the area during the study period 2017 – 2018 was given in Fig 1. Mean daily irradiance along the duration of the experiment was $280 \pm 66 \mu\text{mol PAR m}^{-2} \text{ s}^{-1}$. Mean air temperature for the same period was $35.0 \pm 1.2^\circ\text{C}$, while daily minimum mean was $25.0 \pm 1.0^\circ\text{C}$, and the daily maximum air temperature $36.5 \pm 2.0^\circ\text{C}$. Mean daily water temperature for the experimental period was $31.6 \pm 1.5^\circ\text{C}$, while daily minimum was $20.8 \pm 1.8^\circ\text{C}$. During the period, a maximum rainfall of 129 mm was observed in September and a minimum of 2 mm in April.

Growth Parameters

During the experimental period (60 days), nearly 10% mortality was observed in control plots whereas no mortality was observed in any manure treated plots. This is consistent with the study of Kumar *et al.* (2012) who stated that the survival capacity values of plants were significantly improved by organic manure addition. The results on the effect of FYM and HC on the growth parameters of *S. brachiata* are presented in Table 2. *S. brachiata* has attained a maximum height of 26.7 cm on 60 DAP under sea water irrigation with the supplementation of HC @ 1 ton ha⁻¹.

In general, plant height increased with increasing level of HC up to 1 ton ha⁻¹ (T2) and FYM up to 2 ton ha⁻¹ (T5), beyond this no more significant increases. According to Martinez-Garcia (2010), the decreased growth of *S. brachiata* in control plots were due to drying soil at which they could no longer extract water from the soil. Maximum shoot and root length were observed in T2 (16.3 cm & 10.3 cm) followed by T3 (15.7 cm & 9.43 cm) and T5 (15.3 cm and 9.21 cm). Maximum lateral branches was observed in T2 (11.9) than T0 (6.8). However, throughout the experiment, the number of nodes and side branches on the main stem did not significantly differ among the

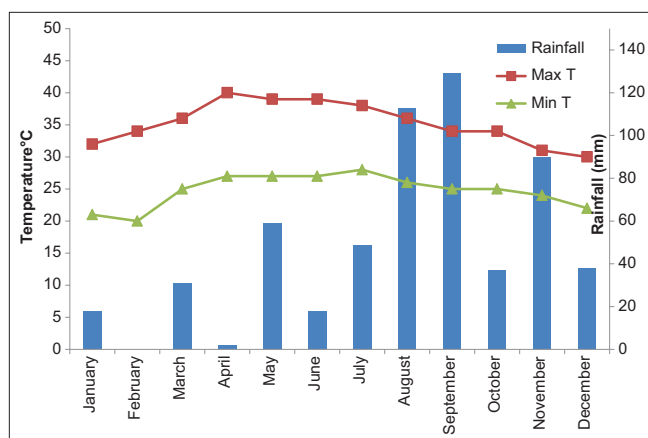


Figure 1: Meteorological data prevailed in the study area during 2017

organic manure treatments. Arya (2017) found that phosphorus application with FYM showed a maximum height increment of 35.9% in *Salvadora persica*, a perennial halophyte under field condition compared to control. Noaman (2004) observed that the differences between fertilizer treatments for different halophyte species regarding plant height were not significant at the initial stage of growth and thereafter the differences became apparent at the third stage (60 DAP). Higher shoot/root ratio in the current study indicated that this halophyte accumulate greater rootstocks with age, which enabled them to withstand high soil salinity levels (Mala *et al.*, 2010). The linear regression analysis indicated significant positive correlation between S: R and biomass productivity ($r^2 = 0.840$) (Fig 2.). Similar results were reported in different glycophytes as well as halophytes under saline conditions. In a previous study, Bai *et al.* (2017) reported that one-time application of dairy manure rapidly increased soil organic matter in mudflat saline soil, which provided good conditions for growth of ryegrass. Sheikhi and Ronaghi (Sheikhi, & Ronaghi, 2013) observed that the application of vermicompost increased plant growth by mitigating the negative effects of high concentrations of Na and Cl in saline soils. Tawfik *et al.* (2019) found that the addition of chicken manure to the soil has been shown to significantly

increase the growth characteristics of *Atriplex* which may be related to the important role of nitrogen, phosphorus and potassium in plant tissues which reflects its vegetative growth. The tissue water content (TWC%) in control plants was higher (73.2%) than the manure treated plants and there was also no significant difference between the treatments. The soil as well as sea water salinity caused a progressive increment in tissue water content, thereby increased the turgor in the leafy shoots of control plants. The capacity of *S. brachiata*, to maintain high TWC in their leaves, despite of high external salinity might have a protective role from the deleterious effects of salinity (Parida *et al.*, 2016). *Salicornia brachiata* supplemented with halophytic compost (1 ton ha⁻¹) has attained a maximum above ground biomass (38.8 g/plant) when compared to control (23.8 g/plant). The plants supplied with HC @ 1 ton ha⁻¹ showed increase in specific growth rate (SGR) (4.36 g m⁻² d⁻¹) followed by FYM @ 2 ton ha⁻¹ (3.59 g m⁻² d⁻¹) as compared to control (Table 3) with a maximum productivity of 0.324 Kg m⁻². Non-significant differences were noted in the values of MSI

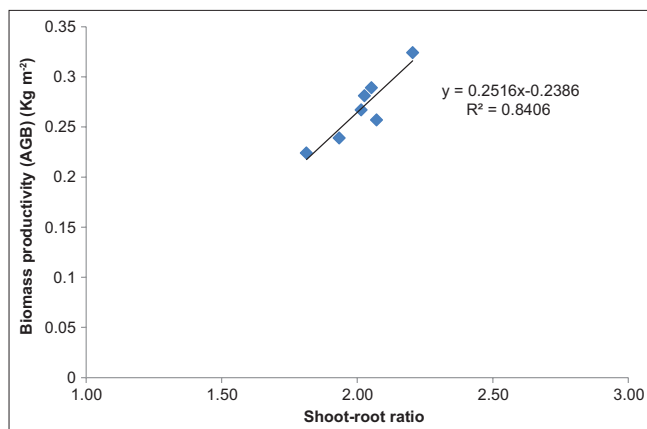


Figure 2: Correlation between Shoot - root ratio and Biomass productivity (AGB) of *Salicornia* under sea water irrigation

and Ls among fertilizer treatments under salinity condition. However, HC and FYM applications significantly decreased MSI, with the optimal effect (36.6%) being noted in the FYM (5 ton ha⁻¹) treatment. Abbasi *et al.* (2014) demonstrated that moderate exogenous K⁺ application may effectively diminish the salinity-induced damage to cellular membrane. Adequate K⁺ supply may reduce the peroxidation of unsaturated fatty acids, and increased content of unsaturated fatty acid helps to improve the membrane fluidity (Zemanová *et al.*, 2015). Our results are supported by Liu *et al.* (2012) who also observed less membrane damage and enhanced growth in *Tamarix chinensis*, *Suaeda salsa*, *Salicornia europaea*, and *Limonium bicolor* under low salinity. Similar results were reported with different biofertilizers in various salt tolerant glycophytes, where the stimulatory effect of biofertilizers is proposed to be mainly due to the bacterial release of nitrogen, phosphorus and indole-3-acetic acid in the rhizosphere (Rothballer *et al.*, 2005). Earlier studies revealed that biofertilizer inoculation reduced the deleterious effects of NaCl on growth, increased the nutritional assimilation of plant (total N, P and K), and also improved soil properties, such as organic matter content and total N in soil (Hamdia *et al.*, 2004).

Biomass Productivity

The organic supplementation in the present study at low level showed significant increase in the halophytic biomass productivity of *S. brachiata* (Table 3). Maximum fresh (28.8g) and dry weight (2.96 g g⁻¹) were observed in plants treated with HC (T2) followed by FYM (T5) (2.38 g g⁻¹) as compared to the control. The increase in fresh weight of the leafy shoots can be attributed to the increase in nodal thickness and the accumulation of ions and water in the tissues (Khan *et al.*, 2009). Soil amendments of HC up to 1 ton ha⁻¹ and FYM up to 2 ton ha⁻¹ exhibited increased above-ground biomass and beyond that biomass production was insignificant. The possible

Table 2: Growth characteristics (60 DAP) of *Salicornia brachiata* cultivated under sea water irrigation

Treatments	SL (cm)	RL (cm)	LB	TWC (%)	MSI (%)
T0	12.2±0.26 ^d	6.73±0.14 ^e	6.8±0.17 ^d	73.2±0.08 ^a	46.4±0.05 ^a
T1	16.8±0.32 ^c	8.11±0.08 ^d	9.3±0.09 ^{bc}	67.2±0.11 ^b	42.6±0.16 ^b
T2	20.9±0.43 ^a	9.48±0.17 ^a	11.9±0.13 ^a	67.1±0.17 ^b	40.6±0.25 ^c
T3	17.9±0.08 ^b	8.83±0.12 ^b	10.3±0.09 ^b	66.2±0.23 ^b	38.6±0.11 ^d
T4	15.7±0.12 ^d	8.12±0.19 ^d	7.3±0.12 ^d	65.4±0.13 ^c	40.4±0.06 ^c
T5	17.3±0.17 ^b	8.43±0.11 ^c	7.9±0.09 ^c	65.2±0.17 ^c	39.1±0.17 ^c
T6	16.2±0.14 ^c	8.09±0.09 ^d	7.1±0.11 ^d	65.1±0.09 ^c	36.6±0.08 ^d

SL: Shoot length; RL: Root length; LB: No. of Lateral branches; TWC: Tissue water content; MSI: Membrane stability index; Values are Mean±SE; Values followed by same letter are not significant at p>0.05

Table 3: Above ground biomass (AGB) and productivity (60 DAP) of *S. brachiata* cultivated under sea water irrigation

Treatments	Fresh weight (g/plant)	Dry weight (g/plant)	Specific Growth rate (g m ⁻² d ⁻¹)	Productivity (Kg m ⁻²)
T0	23.8±0.27 ^d	8.11±0.09 ^e	2.69±0.07 ^d	0.224±0.009 ^d
T1	29.6±0.34 ^c	10.12±0.07 ^c	3.34±0.12 ^c	0.257±0.008 ^c
T2	38.8±0.38 ^a	12.36±0.13 ^a	4.36±0.09 ^a	0.324±0.006 ^a
T3	30.9±0.56 ^{bc}	11.18±0.06 ^b	3.48±0.08 ^b	0.281±0.003 ^b
T4	24.6±0.26 ^d	9.06±0.12 ^d	2.78±0.06 ^d	0.239±0.005 ^d
T5	31.9±0.29 ^b	10.74±0.08 ^{bc}	3.59±0.11 ^b	0.289±0.006 ^b
T6	28.3±0.33 ^c	9.79±0.05 ^d	3.19±0.13 ^c	0.267±0.006 ^c

Values are Mean±SE Values followed by same letter are not significant at p>0.05

reason could be the higher levels of organic supplementation reduced the soil salinity where *S. brachiata* requires high salinity for optimal growth (Mala *et al.*, 2010). Under high salinity, the major growth limitation encountered by halophytes was attributed to nutrient shortages. Radulovich *et al.* (2017) conducted a fertilizer-addition trial and found that *Avicennia* plantlets not receiving fertilizer continued with stagnant growth while those receiving fertilizer rapidly resumed growth and at a larger rate than average. It was observed in the present study that different plant parts were not equally affected by salinity, the growth of shoots in control plants was more suppressed than that of roots. Decrease in root/shoot dry weight ratio of fertilized *S. brachiata* suggested that fertilizer application has supported shoot growth more than root growth even under highly saline conditions. The dry weight increase could be attributed to the accumulation of inorganic salts and organic matter in the plant tissues.

The maximum halophytic productivity of 0.324 kg m⁻² was recorded at 60 DAP from *S. brachiata* grown in saline soils amended with HC @ 1 ton ha⁻¹ (T2) compared to the control (0.224 kg m⁻²). This (approx. 9.84 ton ha⁻¹) was much closer to the production of *S. bigelovii* (11 ton ha⁻¹) at full maturity by Abdal (2009) in sandy soils of coastal areas in Kuwait. The increased biomass production might be due to the application of compost that increases soil organic matter and improves a number of soil properties including water-holding capacity, oxygen content, soil fertility, reduces soil erosion, improves solar heat absorption, increases water infiltration rates, reduces nutrient leaching, which in turn increases crop growth and yields (Hussein *et al.*, 2012). Moreover, the increased halophytic productivity in the saline soils amended with organic manure might be due to the enhanced release of nitrogen from HC and FYM. Similar to our findings, Pandya *et al.* (2010) observed an increase of 51% biomass production in *Salicornia* with the addition of 100 kg N ha⁻¹ over control. Several studies on the nutritional conditions necessary to faster growth of *Salicornia* have identified the need for extremely high quantities of nitrogen fertilizer (Rueda-Puente *et al.*, 2004). Hussein *et al.* (2012) mentioned that the increase in growth characters could be due to that nitrogen sharing in building up and move carbohydrates in plant parts to improve the growth and yield characters. According to Ventura and Sagi (2013), nitrate was the preferred N-source for *Salicornia*, resulting in 60% higher yields compared to ammonium fertilized plants. Similarly, the application of molybdenum as a foliar spray during seawater cultivation enhanced yield by accelerating the activities of both nitrate reductase (NR) and xanthine dehydrogenase (XDH) in plants fed either nitrate or ammonium (Ventura *et al.*, 2013). Abusuwar and Al-Solimani (2013) stated that optimal use of NPK fertilizers enhanced crop yield and forage quality by minimizing Na⁺ toxicity under saline conditions. Balakrishnan *et al.* (2010) observed increased yield parameters such as fresh and dry weight of pod, length and breadth of pod in *Vigna* grown under *Suaeda* compost than other mangrove composts and control. Besides the fertilization in the plants natural habitat, Kudo and Fujiyama (2010) growing *Salicornia* plants in greenhouses reported an increase in biomass with N addition. Our results are on par with Webb *et al.* (2012) who observed an

increase in above-ground growth of *S. europaea* irrigated daily for a short period, with an increase in N concentration up to 4 mmol NH₄⁺ l⁻¹ (0, 2, 4 mmol l⁻¹), and no further increase at 6 mmol l⁻¹.

Photosynthetic Pigments

Chlorophyll is the basis of photosynthesis and its content is a key indicator for plant growth under saline conditions. Salinity admittedly hinders numerous morphophysiological attributes like plant photosynthetic capacity by reducing Chls contents (Abbasi *et al.*, 2014). Under saline condition, the contents of Chl were enhanced by all the level of organic manure application, while those values decreased sharply at control treatment (Table 4). The decrease of chlorophyll is mainly attributed to the elevated cytosolic Na⁺ and Cl⁻ which resulted in both reduce rate of chlorophyll biosynthesis and its faster degradation (Tavakkoli *et al.*, 2011). Similar results had been reported by several workers in a number of halophytes such as *Avicennia* sp. and *Aegiceras corniculatum* (Tejada *et al.*, 2006). Chlorophyll content was statistically differ with the application of HC, FYM and the maximum total chlorophyll was observed in *S. brachiata* at T2 (0.694 mg g⁻¹). The chlorophyll 'a' was always higher than that of chlorophyll 'b' at all levels. Sea water salinity induced significant decreases in chlorophyll contents of *S. brachiata* in control plots whereas, HC and FYM application effectively alleviated the salinity-induced injuries. These results are in agreement with those obtained by El-Quesni *et al.* (2013); they reported that chlorophyll a, b and carotenoids were increased in *Jatropha* seedlings treated with algae, phosphorien, microbial and compost compared to control plants. Tawfik *et al.* (2019) reported that biofertilizer inoculation generally increased the content of chlorophyll a+b as compared with control. Abbasi *et al.* (2014) reported that potassium application may effectively alleviate the salinity-induced decreases of Chl contents of maize hybrids in field conditions. Islam *et al.* (2014) observed significant influence of chlorophyll pigments on shoot biomass, as the amount of sequestered carbon is generally proportional to the overall pigment content in the shoot. This statement can be supported by our observation where leaf shoots with high chlorophyll content had high biomass yield in *S. brachiata* as high chlorophyll content resulted in high photosynthesis rate.

Proximate Analysis

The protein content of *S. brachiata* was increased with the application of vermicompost and farmyard manure compared to control (Table 5). Under sea water irrigation, the maximum protein observed was (23.2 mg g⁻¹) in plants treated with HC @ 1 ton ha⁻¹ (T2) and lowest content (18.1 mg g⁻¹) was observed in control plants (T0). Similar results were observed under field condition where the protein content increased with increasing NaCl concentrations in certain halophytes such as *Helochola setulosa* (Joshi *et al.*, 2002) and *Thellangiella halophila*. In general, the protein content insignificantly differed between the organic manure treatments. Similar results were obtained by Meychik *et al.* (2013) who found that upon a decrease or an increase in NaCl concentration (from 250 to 0.5 or from 250

Table 4: Chlorophyll, proline, phenols and ascorbic acid contents in *S. brachiata* cultivated under sea water irrigation

Treatments	Chl'a (mg g ⁻¹)	Chl'b (mg g ⁻¹)	Proline (μmol g ⁻¹)	Phenol (mg 100 g ⁻¹)	Ascorbic acid (mg 100 g ⁻¹)
T0	0.377±0.08 ^c	0.262±0.12 ^c	42.7±0.21 ^a	1.93±0.19 ^a	6.23±0.31 ^a
T1	0.368±0.11 ^d	0.278±0.11 ^c	36.2±0.35 ^b	1.62±0.13 ^b	5.72±0.12 ^b
T2	0.392±0.13 ^a	0.302±0.09 ^a	36.1±0.23 ^b	1.56±0.16 ^b	5.56±0.26 ^b
T3	0.379±0.05 ^c	0.282±0.05 ^b	35.7±0.19 ^c	1.43±0.11 ^c	4.92±0.17 ^c
T4	0.365±0.07 ^d	0.272±0.11 ^c	36.1±0.26 ^b	1.53±0.17 ^b	5.53±0.21 ^b
T5	0.387±0.06 ^b	0.287±0.07 ^b	35.8±0.16 ^c	1.41±0.14 ^c	5.41±0.34 ^b
T6	0.374±0.11 ^c	0.284±0.13 ^b	35.3±0.14 ^c	1.34±0.28 ^d	4.94±0.28 ^c

Values are Mean±SE; Values followed by same letter are not significant at p>0.05

Table 5: Total sugars, protein, crude fat, crude fibre and calorie value of *S. brachiata* under seawater irrigation

Treatments	Total sugar (mg g ⁻¹)	Protein (mg g ⁻¹)	Crude fat (%)	Crude Fibre (%)	Calorie value (100g)
T0	26.2±0.23 ^c	18.1±0.13 ^c	0.33±0.07 ^d	13.2±0.19 ^c	209.7±2.13 ^e
T1	27.4±0.16 ^c	19.7±0.09 ^b	0.39±0.09 ^b	14.6±0.24 ^b	221.3±2.35 ^d
T2	31.3±0.12 ^a	23.2±0.11 ^a	0.46±0.07 ^a	15.8±0.31 ^a	261.7±2.08 ^a
T3	28.1±0.21 ^b	22.8±0.07 ^a	0.41±0.08 ^b	14.9±0.33 ^b	247.8±1.74 ^b
T4	26.8±0.32 ^c	18.2±0.06 ^c	0.36±0.11 ^c	13.9±0.24 ^c	210.3±2.12 ^e
T5	29.3±0.38 ^{ab}	21.6±0.08 ^{ab}	0.40±0.09 ^b	14.7±0.21 ^b	231.7±1.48 ^c
T6	27.8±0.14 ^c	20.6±0.11 ^b	0.38±0.13 ^c	14.2±0.43 ^{bc}	229.8±2.44 ^c

Values are Mean±SE; Values followed by same letter are not significant at p>0.05

to 750 mM), the amount of protein in root and leaf tissues of *Suaeda altissima* drastically increases. Similarly, *S. brachiata* showed an increasing trend for total sugar content with the addition of HC up to 1 ton ha⁻¹ (31.3 mg g⁻¹) and FYM up to 2 ton ha⁻¹ (29.3 mg g⁻¹) compared to control (Table 5). This corroborates with an earlier report that under salinity, higher amount of total soluble sugars was observed in *S. portulacastrum* (Jothiramshekar *et al.*, 2018). The sea water induced increase in sugar content with increasing age of control plants might be due to the starch-sugar inter-conversion to provide more sugar for osmoprotection (Slama *et al.*, 2015). An increasing sugar content and corresponding decrease in the starch at higher salinities have been reported in several halophytes (Ashraf *et al.*, 2010). As for the interaction effect of saline irrigation and biofertilizer inoculation, the highest values for the crude protein content was recorded in *S. brachiata* plants supplied with halophytic compost @ 1 ton ha⁻¹ and irrigated with full-strength seawater.

Proline content of the leafy shoots of *S. brachiata* was more in control plants than manure treated plants (42.7 μmol g⁻¹). Greater accumulation of proline was observed in the halophytic plant without any soil amendments (42.7 μmol g⁻¹) followed by the applications of HC @ 1 ton ha⁻¹ (36.1 μmol g⁻¹) and FYM @ 5 ton ha⁻¹ (35.3 μmol g⁻¹). There is no significant difference in plants amended with low dose of FYM whereas the increasing level of fertilizer application decreased the accumulation of proline (Table 4). There was a gradual rise in the level of proline on 60th day sampling in control plants when compared to the plants treated with fertilizers. The present observations are in accordance with several studies that proline content progressively increased with high levels of salinity in *Sesuvium portulacastrum* and *Odyssea paucinervis* (Naidoo *et al.*, 2008). Similar to our results, increased level of proline in response to salt stress has been reported in many plants (Zakery-Asl *et al.*, 2014). The total phenol content was varied in the different treatments and ranged from 1.34 to 1.93 mg

GAE g⁻¹DW (Table 4). The maximum total phenol content was observed in control plants (T0) (1.93 mg g⁻¹) followed by HC treated plants where as the variation was insignificant among the FYM treatments. Ventura *et al.* (2011) mentioned that in *Salicornia* and *Sarcocornia*, total polyphenols are high (1.2 and 2.0 mg GAE g⁻¹ FW), such that they are far above the lower limit of other, non-halophytic leafy vegetables rated as rich in phenolic compounds (>0.5 mg GAE g⁻¹ FW) (Isabelle *et al.*, 2010). Many authors have reported salinity induced higher accumulation of polyphenols in many plants (Ksouri *et al.*, 2008; Yuan *et al.*, 2010) in order to counter the salinity induced oxidative damage. Similarly, the total ascorbic acid content was not significantly varied between control and HC treated plants where the maximum content of 6.23 mg 100 g⁻¹ and 5.72 mg 100 g⁻¹ was recorded in control and HC @ 1 ton ha⁻¹ respectively. Lu *et al.* (2010) observed the total ascorbic acid content of 6 mg 100 g⁻¹ fresh product in the highly saline-adapted shoots of *S. bigelovii*, values in the similar range of those for non-halophyte leafy vegetables, such as spinach (7 mg 100 g⁻¹) and lettuce (<2 mg 100 g⁻¹).

Mineral Nutrients and Food Value

The present results clearly indicated that the application of different level of vermicompost and farmyard manure had considerable effects on the different mineral contents of *Salicornia* especially N, P, K, Ca, Cl and Na (Table 6). In the most cases, application of different manure levels resulted in significant increases in the values of N (30%), P (13%), K (30%) and Ca (13%) but the amounts of sodium decreased compared to the control plants. Gradual increases in the above mentioned traits were noticed with the plants which received halophytic compost (1 ton ha⁻¹) followed by FYM (2 ton ha⁻¹). Suitable K⁺/Na⁺ ratio has a key role for maintaining plant growth under saline condition. In the present study, addition of both HC and FYM significantly alleviated the salinity-induced K⁺ deficiency and effectively increase the K⁺/ Na⁺ ratio in

Table 6: Mineral nutrient status of *S. brachiata* cultivated under sea water irrigation

Treatments	N (%)	K (%)	P (%)	Na (mg g ⁻¹)	Ca (mg g ⁻¹)	Cl (mg g ⁻¹)	Mg (mg g ⁻¹)	Fe (mg g ⁻¹)
T0	1.29	5.2	5.8	0.363	0.332	0.732	0.106	0.106
T1	1.36	5.9	6.2	0.342	0.352	0.582	0.153	0.083
T2	1.66	6.7	6.6	0.338	0.381	0.551	0.172	0.112
T3	1.53	6.2	6.5	0.326	0.367	0.517	0.118	0.098
T4	1.31	5.3	5.9	0.332	0.343	0.563	0.138	0.093
T5	1.46	6.1	6.3	0.329	0.361	0.541	0.148	0.109
T6	1.43	5.4	6.1	0.321	0.337	0.513	0.129	0.089

both shoot and root (Grewal, 2010). In addition to this, some earlier reports suggested that halophyte species may substitute K⁺ for Na⁺ to increase turgor pressure rapidly in epidermal cells (Shabala & Mackay, 2011) which can be justified by the higher concentration of K⁺ in *S. brachiata* treated with organic manure. Calcium and magnesium concentrations were extremely low in shoots of control plants compared to fertilizer treated plants agreeing with the results reported earlier for *Salicornia* and other halophytes (Mala *et al.*, 2010). This was supported by Ventura *et al.* (2011) who observed enhanced values for these nutritive ions in *Salicornia* and *Sarcocornia*, whose final contents in edible portions was comparable to those in non-halophyte vegetables grown at moderate salinity. The calorie value of *S. brachiata* was calculated based on the determination of the basic proximate analysis of primary metabolites.

As per the recommendations of USDA the calorie value of the edible halophyte *S. brachiata* was calculated by multiplying the values of carbohydrate (4 times), protein (4 times), crude fibre (2 times) and crude fat (9 times). In our study, we observed that the mean serving of 100g of *S. brachiata* leafy shoots contains a total calorie value of 262, 247 and 209 cultivated under HC @ 1 ton ha⁻¹, FYM @ 2 ton ha⁻¹ and control treatments, respectively. Since the proline content and toxic ionic concentrations were reduced in organic manure treated plants, they exhibited more consumable nature and increased caloric value. We observed in our study, that the amount of crude protein in *S. brachiata* cultivated in HC treated soil could sufficiently meet the minimum protein requirement of adult sheep or cattle i.e., 14 to 18% for growing or lactating animals (Ismail, 2015).

CONCLUSIONS

The present short term field experiment conducted at coastal inlands of Palk Bay region revealed that higher biomass productivity of *S. brachiata* can be achieved under sea water irrigation with the addition of nutrient (N) supplements. This halophytic plant exhibited good adaption to salinity in terms of better plant growth, biomass and defense mechanisms through the accumulation of inorganic ions and development of succulence. The soil studies explained that the soil texture and the inherent soil nutrient levels play a significant role in plant performance in saline situations. Hence, *Salicornia* cultivated with highly saline water, are ideal leafy vegetables containing nutritional metabolites rich in antioxidant compounds that are indispensable to the human diet.

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