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Research Article

Effect of seaweed extract on rice (*Oryza sativa* var. ADT53) productivity and soil fertility in Cauvery delta zone of Tamil Nadu, India

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Abstract
The monocropping of rice in the Deltaic zone deteriorates soil health and crop productivity. Seaweeds are marine resources easily available at negligible cost and also rich in bioactive compounds. A field experiment was conducted at Cauvery Delta zone of Tamil Nadu during summer season2021 to evaluate the bio-efficacy of Seaweed extract on growth, yield, and soil properties of rice, *Oryza sativa* var. ADT53. The experiment was framed in RBD comprising of 12 treatments viz., soil application of Seaweed extract(SWE) @ 12.5kg/ha,25kg/ha, 37.5kg/ha , foliar spraying of SWE gel & liquid @ 0.5% twice at tillering and panicle initiation stages, a combination of soil application and foliar spray and fertilizer alone. Experimental findings revealed that the soil application of SWE @ 12.5kg/ha along with a foliar spray of seaweed liquid recorded higher plant height (121.1cm),dry matter production (11390kg/ha),yield attributes *viz.*, number of grains per panicle (166), panicle length (21.8 cm), thousand grain weight (14.7g), number of productive tillers per m^2 (275), grain yield (5612 kg/ha)and straw yield (7829 kg/ha). However, The soil application of SWE @ 25kg/ha recorded higher soil available nutrients *viz.*,N(260 kg/ha);P(42kg/ha); K(170kg/ha);Ca (27.7meq/100g); Mg(5.5meq/100g);S(18.2mg/kg);Zn (1.17ppm); Fe (33.82ppm); Cu(1.61ppm);Mn(18.97ppm).The study will help sustain rice productivity and soil fertility in the deltaic zone of Tamil Nadu. The soil application of seaweed extract @ 12.5kg/ha along with foliar spraying (0.5% twice) could be a promising option in the rice ecosystem.

Keywords: Crop productivity, *Oryza sativa*, Rice, Seaweed extract, Soil fertility

INTRODUCTION

Rice is the staple food for the whole world. In India,rice is an important food crop that occupies about 44 million ha, with average production and productivity of about 144.52 million tons (2020-21).VanBussel *et al*. (2015) shared that rice shares 52% of area and 46% of production in total cereals under cultivation & production in India. In Tamil Nadu, the rice occupies an area of about 20 million ha, with an average production of nearly 70-80 lakh tonnes. Grassinin *et al*.(2015) reported that the Cauvery Delta region is the main rice cultivated zone of Tamil Nadu, contributing> 50% cultivable area. In this deltaic zone, rice is cultivated continuously as monocropping leads to deteriorating soil health. To sustain soil health economically, judicious application of chemical fertilizers and organic sources is essential. Due to the limited organic sources, the farmers need alternate one to improve the soil quality. In this context, seaweed is an alternative organic source that could be cheaply available and rich in growth-promoting substances.

Raghunandan *et al*. (2019) reported that seaweeds are important marine algae with admirable qualities of being renewable, biodegradable,flexible, non-toxic and tenacious. In India, 700 species of marine algae were found in both tidal and deep-water regions of the Indian coast. Among that, 60 species were commercially important. The seaweeds (macroalgae) were classified into three categories: brown algae, red algae, and green algae based on their pigmentation. They are abundantly grown along the coastal reserves in many parts of India, *viz*., Tamil Nadu, Gujarat, Goa, Maharashtra, West Bengal & Orissa. Mirparsa *et al*. (2016) reported that, in sunflower, the seaweeds are known to add major plant nutrients viz., N, P,K, Ca, Mg, S, and different micronutrients and trace elements which required for crop growth and development. Arioli *et al*. (2015) noted that these weeds spp. *Kappaphycus alvarezii* is one of the macroscopic marine creatures grown in an intertidal and subtidal area where photosynthetic light 0.1% is available. Further, seaweeds are rich in organic compounds viz., proteins, amino acids, fat, cellulose, hemicellulose, lignin, vitamins (Raghunandan *et al*., 2019). Many studies pertaining to plant growth-promoting effects of seaweed have been reported by Shimaa *et al*. (2016). In fact, the plant growth-promoting seaweed substances in Arabidopsis influence the biosynthetic pathways of phytohormones in plants (Jithesh *et al*., 2012) and a rich amount of auxin, gibberellins, cytokinins and antibiotics boost the growth and yield of soyabean (Mathur *et al*., 2015). Pacholczak*et al*.(2016) have proven that in nine bark stem cuttings (Physocarpusopulifolius), the seaweed was the novel source of antioxidants and plant hormones osmoprotectants, plant nutrients and also bioactive metabolites of pharmaceutical and industrial significance. Evenni *et al*. (2015) reported that the seaweed extract from the brown seaweed stimulated the seed germination, root development, increased nutrient uptake, resistance to fungi and bacteria.Nabti*et al*. (2010) proved that, in wheat, the seaweed application achieves higher yields with better plant and soil health restoration under high salinity conditions. Sunarpi *et al*. (2011) reported that in rice, the utilization of seaweed-based products has reduced the doses of nitrogen, phosphorus and potassic fertilizers and also induced the seed germination and growth parameters strongly than chemical fertilizers in corn (Partani., 2013). Haider *et al*. (2012) noted that the foliar spraying of seaweed extract improved the protein content, total soluble solids and nitrogen content of potato tubers. Rathinapriya *et al*. (2020) reported that, in foxtail millet, the application of liquid seaweed extracts improved plant growth and yield attributes and enhanced soil quality. Hussain *et al*. (2021) reported that the foliar application of seaweed extract in tomato had improved the soil microbial communities, available nitrogen, and soil health. Manea*and* Abbas (2018) suggested that in Broccolithe foliar application of seaweed extract enhanced the cabbage quality and quantity. So the seaweed is one of the most reliable organic materials, which could improve the crop yield and quality of the soil. Hence to study the influence of seaweed extract in the monocropping of rice, the present research was initiated with the rice (*Oryza sativa*)var. ADT 53 in Cauvery Delta Zone of Tamil Nadu.

MATERIALS AND METHODS

The present experimental study was conducted at the Tamil Nadu Rice Research Institute, Aduthurai, Thanjavur district, representing the Cauvery Delta Zone of Tamil Nadu during summer season 2021 with high yielding rice variety ADT 53. The soil texture of the experiment site is clay loam belong to Vertisol (soil order). The experiment was laid out in Randomized Block Design (RBD) with twelve treatments and three replications. The treatments comprised of soil application, foliar spray of seaweed products and combinations as mentioned in Table 1. All the treatments received an equal amount of recommended dose of fertilizer. As per the STCR (Soil Test Crop Response) recommendation,the entire dose of phosphorus (76kg/ha) was applied as basal and the remaining N & K were applied as the split application of about 165kg/ha and 70kg/ha respectively. The observations *viz*., the plant height, dry matter production (DMP), Leaf Area Index (LAI), SPAD reading, root volume and root length in each plot at the interval of 30, 60, 90 DAS and harvest were taken from randomly five plants. The yield parameters viz., no grains/panicles, no productive tillers/m2, thousand grain weight, panicle length were recorded at the harvesting stage from randomly 25 hills in each plot. The post-harvest data on grain yield, straw yield and harvest index were recorded and statistically analyzed using AGRES. The post-harvest soil samples were collected and analyzed for the soil fertility parameters-the initial soil parameters arere depicted in Table 2. The

Table 1. Treatment schedule for field experiments at Cauvery Delta zone

T_1	SWE gel soil application 12.5 kg/ha
T_2	SWE gel soil application 25 kg/ha
T_3	SWE gel soil application 37.5 kg/ha
T_4	Foliar spraying of SWE gel 0.5 per cent (v/v) at tillering + Panicle initiation stage
T_5	Foliar spraying of SWE liquid 0.5per cent (v/v) at tillering + Panicle initiation stage
T_6	SWE gel soil application 12.5 kg/ha+T_4
T_7	SWE gel soil application 25 kg/ha + T_4
T_8	SWE gel soil application 37.5 kg/ha + T_4
T_9	SWE gel soil application 12.5 kg/ha+T_5
T_{10}	SWE gel soil application 25 kg/ha + T_5
T_{11}	SWE gel soil application 37.5 kg/ha + T_5
T_{12}	Control (fertilizer alone)

soil characteristics were estimated by using standard analytical methods *viz*., Organic carbon by Chromic acid wet digestion (Walkey and Black 1934), available Nitrogen by alkaline permanganate method (Subbiah and Asija 1956), available phosphorus by 0.5 $NaHCO_3$ (pH-8.5) (Olsen 1954), available potassium by Neutral Normal Ammonium Acetate Method (Stanford and English 1949), Exchangeable calcium and magnesium by Neutral Ammonium Acetate (pH – 7.0), available sulphur by 0.15% $CaCl_2$ (Chesnin and Yien 1950) and available Micronutrients viz., Fe , Zn, Cu and Mn (Lindsay and Norvell 1979).

Table 2. Initial soil parameters of the experimental site at Cauvery delta zone of Tamil Nadu

organic carbon content (%)	0.6%
pH	7.4
EC (dsm^{-1})	0.47 dsm^{-1}
available N (kg/ha)	243 kg/ha
available P (kg/ha)	47 kg/ha
available K (kg/ha)	170 kg/ha
Exchangeable Ca (meq/100g)	12.3 meq/100g
Exchangeable Mg (meq/100g)	2.4 meq/100g
available Sulphur (mg/kg)	8.8 mg/kg
available Fe (ppm)	31.85 ppm
available Zn (ppm)	0.80 ppm
available Cu (ppm)	1.74 ppm
available Mn (ppm)	22.16 ppm

RESULTS AND DISCUSSION

In rice (*Oryza sativa*) var. ADT 53, the plant growth and yield attributes as well as soil properties were highly influenced by both soil and foliar application of seaweed extract.

Effect of seaweed extract on growth parameters of rice

The seaweed application highly influenced the plant growth parameters. Higher plant height is depicted at T_9(soil application of SWE @ 12.5 kg/ha + foliar application of SWE liquid @ 0.5%) of 46.4cmwhich was on par with T_8(41.8 cm) and T_7(42.3cm) and the lowest plant height was recorded in T_{12} (32.6cm) in 30 DAS. The same trend of results was observed in 60 DAS and90DAS(Table 3). The increased plant height in T_9 might be due to plant hormones, plant growth regulators like auxin, gibberellins, cytokinin, macro and microelements in the SWE,which elicit the strong physiological response at a low dose of concentration. The results are in line with Pramanick*et al*. (2013) who reported that the foliar application of 15% seaweed extract in green gram improved the crop quality and nutrient uptake (N,P, K and micronutrients). Dilavarnaik*et al.* (2017)also reported that in hybrid maize the foliar application of seaweed at 15% concentration either *Kapp aphycusalvareziii* (K sap) or *Gracilaria edulis* (Gsap) significantly improved the cell wall plasticity, apical dominance, meristematic growth and translocation of photo synthetase.

Leaf Area Index (LAI) was recorded higher underT_9were 2.5, 6.6and8.5, which was on par with T_{10} (2.4, 6.4and8.4)and the least LAI was recorded in $T_{4,}$ which was on par with T_5(1.6, 5.6 and 7.7) and T_{12}(1.5, 5.5and 7.2) at 30 DAS, 60 DAS and 90 DAS (Table 3). The increased LAI might be due to the presence of bioactive substances present in the SWE, which could

Table 3. Influence of seaweed extract on plant height and LAI of rice

Treatments	Plant height (cm)			LAI		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1	37.4	59.3	82.6	2.1	5.8	8.2
T_2	36.1	57.9	80.7	1.9	5.7	7.9
T_3	35.5	56.8	78.8	1.8	5.7	7.7
T_4	32.8	50.9	72.4	1.6	5.5	7.4
T_5	33.6	53.4	75.2	1.6	5.6	7.7
T_6	42.7	63.4	87.4	2.3	6.2	8.3
T_7	42.3	62.6	86.3	2.2	6.1	8.3
T_8	41.8	62.0	85.2	2.1	5.9	8.2
T_9	46.4	68.6	92.9	2.5	6.6	8.5
T_{10}	45.4	67.4	91.4	2.4	6.4	8.4
T_{11}	44.5	66.0	90.1	2.3	6.4	8.4
T_{12}	32.6	47.7	71.3	1.5	5.5	7.2
Sed	1.2	1.5	2.4	0.1	0.1	0.2
CD(P=0.05)	2.4	3.2	4.8	0.2	0.3	0.3

have improved the stomatal uptake efficiency. Similar findings were reported by Rathore *et al.(*2009)in soybean that the foliar spraying of 15% seaweed extract could have enhanced the leaf area index, stomatal efficiency, and improved yield.

The higher value of SPAD reading was also recorded in T_9 (44.8) followed by T_{10} (43.2) and T_{11} (42.8). The lowest SPAD reading was revealed in T_{12} (37.3)in 30 DAS. A similar trend of results was also observed in 60 DAS and 90 DAS (Table 4). The higher SPAD value in T_9 might be due to plant growth stimulating substances like betaines and inorganic salts that might have increased the chloroplast size, granular development and chlorophyll concentration in the leaf surface. Similar results were reported by Whaphamet *al*. (1993) that, in cucumber cotyledons, the low concentration of betaines in seaweed extract has incrementally increased the SPAD reading at flowering stage and later it declined due to the development of fibrous material in plant tissues. The result on DMP showed that a high value was recorded under T_9(4374kg/ha), which was followed by T_{10} (4197 kg/ha) and it was on par with T_{11} (4081 kg/ha)and the lower values was recorded under T_4(3422 kg/ha) and T_{12}(3350 kg/ha) at 30 DAS. The same trend of results was also observed in 60 DAS and 90 DAS (Table 4). Compared with the other treatments, T_9 showed better improvement over the control due to the presence of growth-promoting substances and photo synthase in seaweed might lead to the upliftment of DMP. Pramanicket *al.* (2017)also suggested that in potato tubers, the foliar application of *Kappaphycus* sap with the concentration of 7.5% along with 100% RDF recorded higher dry matter production, crop yield and quality of potato. Similar results werealso reported by Rayorath *et al*. (2008) in barley, who reported that the lower dose of SWE at 15% concentration would improve the nutrient mobilization, partitioning, development of vigorous root system and enhancing the plant height, leaf area index, chlorophyll content.

Effect of seaweed extract on root length and volume of rice

The root length and root volume were also enhanced by SWE application (Table 5).The treatment T_9 achieved higher root length on 30 DAS, 60 DAS and 90 DAS (18.9 cm, 23.8cm and 25.9cm) and statistically on par with T_{10} (18.2 cm, 23.2cmand 25.5cm) and T_{11}(17.4cm, 23cm and 24.7cm) and lowest value was recorded in T_{12}(14.7cm, 18.2cm and 21.5cm)(Table 5).

Similar findings were also reported by Kumar *et al*. (2020) that in paddy, the RDF along with two times SoliGroGr (*Ascophyllum nodosum*) @ 10kg/ha improved the nutrient uptake by roots, water and nutrient use efficiency as well as enhanced the plant growth, root development and vigour of the plant. In the present study, the treatment T_9had registered higher root volume (17.5ml), which was statistically on par with T_{10} (17.1ml) and T_{11}(16.4ml) and the lowest value was recorded under T_{12}(11.4ml) on 30 DAS. A similar trend of results was also observed in 60 DAS and 90DAS (Table 5). Rayorath *et al*. (2008)also reported that in Arabidopsis leaves, the foliar application of seaweed extract at very low concentration improved the root growth and volume, which would have stimulated the cell division of root cells and produced more lateral root growth and root biomass. Selvaraj *et al*. (2004) reported that in Okra the foliar application of liquid seaweed fertilizer @ 2.5% enhancing the microbial diversity and nutrient mobilization and mineralization. Dogra *et al.* (2012) reported that in onion, the soil application of seaweed granules @ 2.5g/m^2 recorded maximum shoot height and number of shoot per plant and lowest dis-

Table 4. Influence of seaweed extract on dry matter production and SPAD of rice

Treatments	DMP (kg/ha)			SPAD		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1	3588	5211	7605	41.2	41.1	30.7
T_2	3520	5104	7559	40.7	40.8	30.5
T_3	3505	4911	7442	39.8	39.6	29.3
T_4	3422	4668	7295	39.1	38.7	26.4
T_5	3459	4864	7363	39.2	39.2	28.9
T_6	3930	5365	8146	42.3	42.1	32.8
T_7	3790	5314	7971	42.1	41.7	32.2
T_8	3698	5263	7881	41.6	41.3	31.3
T_9	4374	5667	8437	44.8	44.0	34.8
T_{10}	4197	5574	8354	43.2	42.7	33.5
T_{11}	4081	5459	8224	42.8	42.3	33.4
T_{12}	3350	4592	7123	37.3	37.5	24.1
Sed	105	105	96	0.6	0.9	0.8
CD(P=0.05)	219	217	199	1.2	1.9	1.7

Table 5. Influence of seaweed extract on root length and root volume of rice

Treatments	30 DAS		60 DAS		90 DAS	
	Root Volume (ml)	Root length (cm)	Root Volume (ml)	Root length (cm)	Root Volume (ml)	Root length (cm)
T_1	14.4	15.6	22.3	20.9	29.2	23.1
T_2	13.5	14.7	21.9	20.3	28.1	22.8
T_3	13.2	14.5	20.6	19.9	27.7	22.2
T_4	11.5	14.9	18.5	19.1	26.2	20.5
T_5	12.4	14.8	19.1	18.9	27.2	21.3
T_6	15.9	16.8	23.5	22.7	33.3	24.3
T_7	15.0	16.4	23.0	22.0	32.2	23.9
T_8	14.8	16.4	22.7	21.8	30.5	23.5
T_9	17.5	18.9	25.6	23.8	36.6	25.9
T_{10}	17.1	18.2	24.9	23.2	35.9	25.5
T_{11}	16.4	17.4	23.7	23.0	34.3	24.7
T_{12}	11.4	14.7	18.4	18.2	26.9	21.5
Sed	0.8	1.1	1.5	1.8	1.7	1.4
CD(P=0.05)	1.8	2.3	3.2	3.7	3.6	2.8

Table 6. Influence of seaweed extract on yield parameters of rice

Treatments	Harvest stage				
	1000 grain weight (g)	Panicle length (cm)	No of grains/panicle (Nos)	No of productive tillers/ m^2 (Nos)	Harvest Index (HI)
T_1	14.6	18.4	155	239	44.0
T_2	14.6	18.1	153	232	43.7
T_3	14.5	18.8	152	230	43.5
T_4	14.6	18.4	147	223	42.4
T_5	14.5	18.6	148	225	42.6
T_6	14.6	19.6	159	252	42.5
T_7	14.6	19.2	158	246	42.3
T_8	14.6	19.5	156	239	41.3
T_9	14.7	21.8	166	275	42.0
T_{10}	14.6	21.5	164	269	42.0
T_{11}	14.6	21.3	162	260	42.2
T_{12}	14.5	18.3	145	220	41.7
SEd	NS	1.0	2.8	8.4	0.5
CD(P=0.05)	NS	2.1	5.9	17.5	1.0

ease severity. Selvaraj *et al.* (2004) reported that in *Abelmoschus esculentus*, the application of seaweed liquid fertilizer improved the growth and yield parameters.

Effect of seaweed extract on yield attributes of rice

Total yield may appraise to be the mirror of all the growth and yield features. Higher yield attributes were recorded under T_9 (soil application of SWE @ 12.5 kg/ ha + Foliar spraying of SWE liquid @ 0.5%) viz, no of grains/ panicle - 166, panicle length - 21.8 cm, no of productive tillers m^{-2}- 275 which was on par with T_{10}(no of grains/ panicle - 164, panicle length - 21.5 cm, no of productive tillers m^{-2}– 269) and T_{11}(no of grains/ panicle - 162, panicle length - 21.3 cm, no of productive tillers m^{-2}- 260). The lowest value was recorded under T_{12} (no of grains/ panicle - 145, panicle length -18.3 cm, no of productive tillers m^{-2}- 220), which was on par with T_4 (no of grains/ panicle - 147, panicle length -18.4 cm, no of productive tillers m^{-2}– 223)and T_5 (no of grains/ panicle - 148, panicle length- 18.6 cm, no of productive tillers m^{-2}- 225)(Table 6).The higher yield attributes in T_9 might be due to the presence of bio-stimulant, which energizes the chlorophyll production, photosynthetic process, and thereby boosting vegetative growth. The results matched with Ishwarya *et al*. (2019), who observed that in green gram, the seed soaking in 0.1%

seaweed extract solution for 30 minutes along with the foliar application of seaweed extract 0.25% twice increased the plant height, root volume, number of branches significantly. Singh *et al*. (2015) reported that the rice fertilized with 100% RDF produced higher productive tillers, number of grains per panicle, panicle length resulting in higher grain and straw yield in rice.

Regarding the grain yield and straw yield in the present study, treatment T_9 revealed the highest grain yield (5612 kg/ha), which was on par with T_{10}(5588 kg/ha) and T_{11}(5471 kg/ha). The lowest grain yield was recorded under T_{12}(4645kg/ha), which was on par with T_4 (4790kg/ha) (Fig.1). The treatment T_9 recorded a higher straw yield (7829 kg/ha) which was on par with T_{10} (7691kg/ha) and the lowest straw yield was recorded under T_{12}(6492 kg/ha), which was on par with T_4 (6501kg/ha) and T_5(6543kg/ha) (Fig. 2). The percent increase of grain yield and straw yield in T_9 was 18 - 20% over the recommended dose of fertilizer alone. The increased yield might be due to readily available nutrients like N, P, K, and trace mineral elements in the seaweed. The similar results were reported by Nayak *et al*.(2020) that in rice, the application of 75% RDF + Amaze-x granule @ 10kg/ha + Proventus DS legacy spray @ 625ml/ha observed higher panicle length, the number of filled grains per panicle resulting higher grain and straw yield. The positive influence of seaweed extract as biostimulant in aerobic rice enhanced crops' growth and yield, as reported by Anil *et al*. (2014). Leindah*et al*.(2015) also noted that the spraying of seaweed extract on the foliage of rice @ 15% K sap with 100% RDF recorded higher growth and yield parameters viz., no of productive tillers/hill, panicle length, test weight, grain yield and straw yield. It was found that yield of grain was increased significantly by 11.80% over the control (100% RDF).Pal *et al*. (2015) reported that in maize, the foliar application of seaweed extract @ 15% *Gracilaria*(G sap) along with RDF observed higher growth parameters, yield attributes viz., cob length, no of grain per row, green cob yield and fodder yield. The results are in line with Dwivedi et al. (2014), who proved that in Blackgram, the foliar application of 15% Kappaphycus sap and RDF resulted in an increase by 49.2% grain yield compared to RDF to control (water spray+ RDF). Arun *et al*.(2019) reported that in rice under the transplanted condition, the application of liquid bio-stimulant LBS6_ S obtained higher yield attributes due to effective utilization of native as well as applied nutrients. Deshmukh *et al*. (2013) also showed that applying seaweed extract @ 1500 g/ha in sugarcane and RDF increased cane yield by 14% and sugar yield by 23.1%.

Effect of seaweed extract on soil properties of rice

The results obtained from the post-harvest soil analysis are depicted in Table 7.There is no significant difference in pH and ECvalues after applying SWE. Cation exchange capacity (CEC) and organic carbon determined the nutrient status of the soil fertility. High value of Cation exchange capacity was reported under T_2 (39.7 c mol (+) kg^{-1}) followed by T_1(37.6 c mol (+) kg^{-1}) and the lowest value was recorded under T_{12}(27.2 c mol (+) kg^{-1}), which was on par with T_4 (27.7 c mol (+) kg^{-1}). Organic carbon was reported higher under T_2 (0.96%) followed by T_1 (0.90%) and the lowest value was recorded under T_{12}(0.53%), which was on par with T_4 (0.55%)(Table 7). The higher Cation Exchange capacity and Organic carbon in T_2 might be due to the slow decomposition rate of soil carbon in rice cultivation and the highest carbon stock in seaweed. Dominguez *et al*. (2014) reported that the seaweed extracts in tomatoes restore plant growth in high pH and temperate conditions and Arthur *et al*. (2013)noted that the Kelpak (a liquid seaweed concentrate made from the kelp Ecklonia maxima) is most effective in neutral pHs, it can be used to promote plant grow that low pH and water stress conditions.

The treatment T_2(soil application of SWE @ 25kg/ha) had the numerically higher amount of available nitrogen (259 kg/ha), which was on par with T_1(253 kg/ha) and

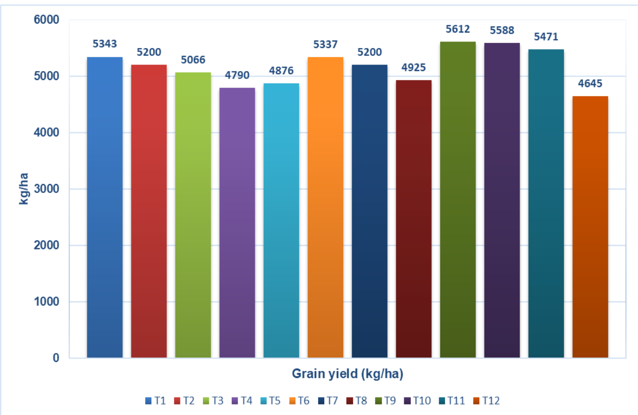

Fig 1. *Grain yield in respective treatments expressed in kgha^{-1}*

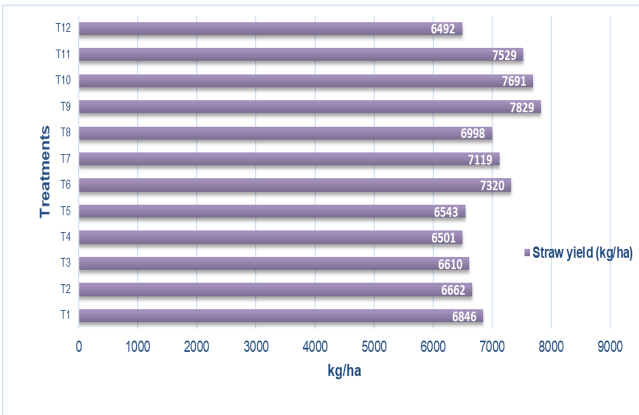

Fig 2. *Straw yield in respective treatments expressed in kgha^{-1}*

T_3 (252 kg/ha) and lower value was recorded under T_{12} (216 kg/ha) which was on par with T_4 (218 kg/ha) andT_5 (215 kg/ha) (Fig 3). The high value of available phosphorus (42kg/ha) had registered under T_2 (soil application of SWE @ 25kg/ha) followed by T_1 (40 kg/ha) which was on par with T_3 (40 kg/ha) and least was observed under T_{12} (31 kg/ha) which was on par with T_4 (32 kg/ha) (Fig 4). The amount of available potassium was numerically higher under T_2(170kg/ha), which was on par with T_1 (168 kg/ha) and T_3 (169 kg/ha) and the least was recorded in T_{12} (144 kg/ha) which was on par with T_4 (146 kg/ha) and T_5 (146 kg/ha)(Fig 3). A similar result was reported by Pramanick *et al*. (2014) in rice wih the application of seaweed extract @ 15% released more plant nutrients, especially nitrates, ammonium & phosphates into the soil, thereby increasing uptake of plant nutrients in sandy clay loam soil of BCKV, West Bengal. Singh *et al*. (2015) reported that the rice fertilized with 100% RDF produced higher nitrogen, phosphorus, potassium and sulphur uptake in grain and straw than 50% recommended fertilizer.

The high value of Exchangeable Calcium (27.7meq/100g) was registered underT_2 (soil application of SWE @ 25kg/ha) followed by T_1 (24.2 meq/100g) which was on par with T_3 (21.9 meq/100g) and lower value was recorded under T_{12} (15.9 meq/100g) which was on par withT_4 (16.8 meq/100g) and T_5 (17.2 meq/100g). Exchangeable magnesium (5.5meq/100g) was recorded higher underT_2 (soil application of SWE @ 25kg/ha) followed by T_1 (4.9 meq/100g) which was on par with T_3 (4.4 meq/100g) and least was recorded under T_{12} (3.2 meq/100g) which was on par with T_4 (3.4 meq/100g) and T_5 (3.4meq/100g) (Table 5). The amount of available Sulphur was higher in T_2 (18.2 mg/kg) followed by T_1 (17.3 mg/kg) which was on par with T_3 (15.9 mg/kg) and the treatment T_{12} (10.1 mg/kg) recorded a lower amount of available Sulphur (Table 7). Similar findings by Ghosh *et al*. (2020) reported for blackgram in sandy loam soil of the red and lateritic belt of West Bengal with the application of seaweed @ 15% *Kappaphycus* + RDF, resulting in higher availability and absorption of inorganic elements such as Ca, Na, K, Mg, N, Cu, Zn etc.

The treatment T_2 (soil application of SWE @ 25kg/ha) recorded higher amount of available zinc (1.17ppm) followed by T_1(1.08 ppm) which was on par with T_3 (1.04 ppm) and less amount of available zinc (0.32 ppm) was reported in T_{12}. The amount of available Fe was showed a higher value under T_2 (33.82ppm), which was on par with T_1 (31.84 ppm) and least was recorded under T_{12} (13.67 ppm), which was on par with T_4 (14.74ppm) (Table 7). A higher amount of available Cu was observed under T_2 (1.61ppm) followed by T_1 (1.44 ppm) which was on par with T_3(1.37 ppm) and a lower value was reported under T_{12} (0.67ppm). The available

Table 7. Influence of seaweed extract on organic carbon,available Ca, Mg, S and Micronutrients of rice

Treatments	Harvest stage										
	pH	EC (dsm^{-1})	CEC c mol(+)kg^{-1}	OC (%)	Ca (meq/100g)	Mg (meq/100g)	S (mg/kg)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)
T_1	7.0	0.50	37.6	0.90	24.3	4.8	17.3	1.08	31.84	1.44	17.12
T_2	7.0	0.51	39.7	0.96	27.7	5.5	18.2	1.17	33.82	1.61	18.97
T_3	7.1	0.50	34.7	0.80	21.8	4.4	15.9	1.04	30.36	1.37	15.12
T_4	7.0	0.50	27.8	0.55	16.8	3.4	10.9	0.41	14.74	0.76	8.85
T_5	7.1	0.51	29.2	0.58	17.2	3.4	11.9	0.47	18.57	0.81	9.28
T_6	7.1	0.50	31.8	0.75	21.3	4.3	14.7	0.85	26.76	1.12	13.21
T_7	7.0	0.50	32.7	0.77	22.0	4.4	15.0	0.87	29.07	1.22	14.39
T_8	6.9	0.51	32.3	0.72	20.8	4.2	14.7	0.79	25.72	1.10	12.43
T_9	7.1	0.49	30.1	0.67	19.4	3.9	13.0	0.62	22.46	0.94	11.45
T_{10}	7.0	0.51	31.1	0.70	19.7	3.9	13.6	0.68	24.31	0.99	12.02
T_{11}	7.1	0.50	29.5	0.64	18.8	3.8	12.8	0.54	22.01	0.89	11.09
T_{12}	6.9	0.49	27.2	0.53	15.9	3.2	10.1	0.32	13.67	0.67	8.64
Sed	NS	NS	0.6	0.03	0.7	0.1	0.5	0.04	1.01	0.03	0.56
CD(P=0.05)	NS	NS	1.3	0.06	1.4	0.3	0.9	0.08	2.08	0.06	1.17

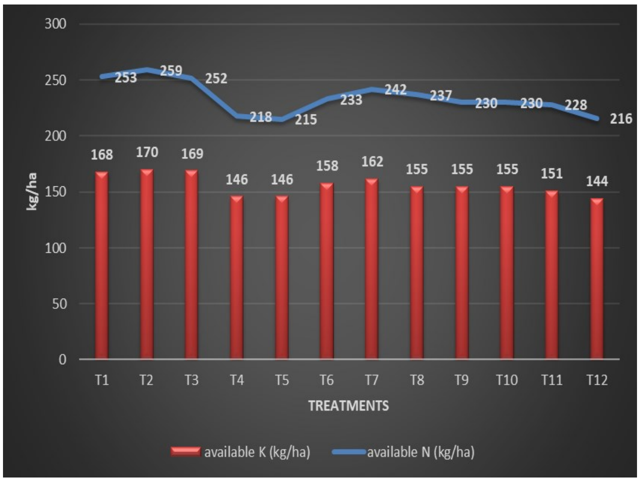

Fig 3. *Nutrient uptake of nitrogen and potassium in various treatments expressed in kgha*$^{-1}$

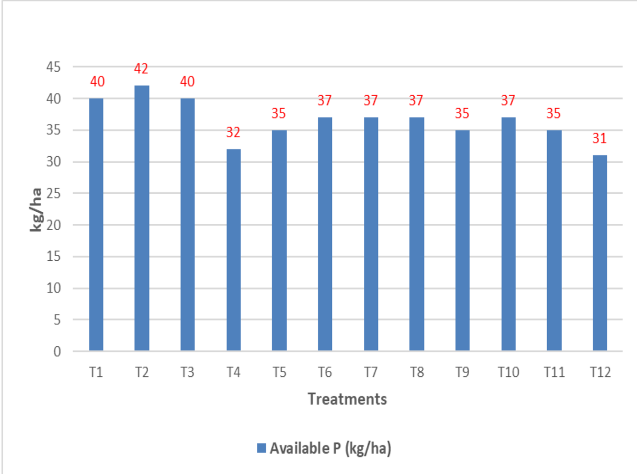

Fig 4. *Phosphorus uptake in various treatments expressed in kg ha*$^{-1}$

Mn (18.97 ppm) was higher under T_2 (18.97 ppm) followed by T_1 (17.12 ppm) and the least was recorded under T_{12} (8.64 ppm), which was on par with T_4(8.85 ppm)and T_5 (9.28 ppm) (Table 7). Layek*et al*.(2017) reported that in clay loam soil of eastern Himalayas, the application of *K. alvarezii* (K sap) or *Gracilaria edulis* (G sap) at 10% along with 100%RDF increased micro-nutrient (Fe, Cu, Mn and Zn) and protein content in rice. Pal *et al*.(2015) reported for maize that the foliar application of seaweed extract @ 15% *Gracilaria* (G sap) along with RDF observed higher available nutrients viz., N, P,K, Ca, Mg and micronutrients. Nayak *et al*.(2020) showed that in rice the application of 100% RDF + Biozyme granule @ 15 kg/ha observed higher organic carbon, available nitrogen, phosphorus and potassium in sandy loam soil of BCKV, West Bengal. Raverkar*et al*. (2016) noted that in green gram, the foliar spraying of seaweed saps @ 10% *Kappaphycus* sap along with RDF increased the grain nitrogen content, protein content and inorganic elements viz., Ca, Na, K, Mg, Zn.Bhattacharya *et al*. (2020) described that the seaweed biorefinery made a great effort towards improved utilization of biomass with a low water footprint and minimal effluent discharge.

Though there is research available on the role of seaweed on different crops, the information regarding seaweed on improving the rice crop yield and soil quality is lagging. The present study mainly focused on the Cauvery delta zone because more than 90% of the area is under rice cultivation and the nature of the soil was heavy clayey textured. The soil fertility was getting declined due to continuous rice cultivation. So the seaweed application, one of the organic sources which boot the soil ecology and soil health in a most prominent way through the soil and foliar on rice productivity and soil fertility in this Cauvery delta zone, is highly essential.

Conclusion

The study on the influence of the seaweed extract *K. alvarezii*on the rice crop (*O. sativa*) var. ADT53 yield and soil fertility concluded that the soil application of seaweed extract @ 12.5 kg/ha along with the foliar spraying of seaweed extract liquid @0.5% twice at tillering and panicle initiation stage had higher crop growth parameters like plant height, LAI, DMP & SPAD and yield parameters *viz*., no of grains/panicle, panicle length, no of productive tillers/m^2, grain yield and straw yield. The rice yield was also increased by 18 -20% over the recommended dose of fertilizer. However, the soil application of seaweed extract @ 25 kg/ha was found to be superior in improving the available nutrients like N, P, K, Ca, Mg, S and micronutrients. The recommendation emanated from the study for the deltaic farmers is the soil application of seaweed extract along with foliar spray @ 0.5 % twice at tillering and panicle initiation stage for enhancing the rice productivity and soil fertility.

Conflict of interest

The authors declare that they have no conflict of interest.

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