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Sustainable agro-technology for enhancement of rice production in the red and lateritic soils using seaweed based biostimulants

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A field trial was conducted to evaluate the efficacy of *Kappaphycus* and *Gracilaria* based seaweed extracts (SWEs) to enhance the yield of rice in red and lateritic soils and also simultaneously assess the sustainability of the use of SWEs through life cycle assessment. A total of thirteen treatments involving combinations of recommended rate of fertilizers (RRF) 80: 40: 40 N: P_2O_5: K_2O kg ha^{-1} and SWEs applied at concentrations (2.5, 5, 7.5, 10 and 15%) were tested along with a suitable control (water spray + RRF) in a randomized block design. The efficacy of SWEs at 7.5% was also tested with lower dose of RRF (50% RRF). The SWEs were foliar applied 25, 50, and 70 d after transplanting of rice. Life cycle impact assessment (LCIA) for the production of fertilizers and SWEs required for 1ha of rice cultivation was carried out using ReCiPe Midpoint method and were expressed as impacts t^{-1} of rice production. Combined analysis of data of the experiment revealed that SWEs from *Kappaphycus* (KSWE) and *Gracilaria* (GSWE) when applied at 15% concentration significantly increased the grain yield of rice by 29% and 28%, respectively, over control; however, SWEs at 10% gave more net benefit per unit investment compared to the control. Notably, the grain yield in the treatments involving combination of SWEs with 50% RRF was statistically at par with control. LCIA revealed that in comparison to the control, maximum reductions of 11.4% and 14.8% in climate change (CC) impact category t^{-1} of rice were obtained in treatments involving combination of RRF with 15% KSWE and 10% GSWE, respectively. Interestingly, treatments involving 50% RRF + SWEs brought about at least 43% reduction in CC impact t^{-1} of rice, which amounts to savings of about 35 kg CO_2-equivalents t^{-1} of rice. Similarly, reductions were also observed for other impact categories. SWEs offer great promise in global perspective towards mitigating climate change as well as other environmental impacts and sustainably increasing rice yield.

1. Introduction

India is the world's second largest producer and largest exporter of rice. With 44 M ha, India ranks number one globally in paddy area and with 104 Mt (Arya and Kumar, 2014) stands next only to China in total paddy production. However, the productivity of rice is low in India (3721 kg ha^{-1}) when compared to the world average of 4548 kg ha^{-1} and other leading rice growing countries like China 6775 kg ha^{-1} (Bodh and Rai, 2015). Rice productivity is constrained by edaphic (soil) conditions. It is a challenge to cultivate crops in red and laterite soils (a clayey soil horizon rich in iron and aluminium oxides) because of its low fertility, acidic pH, low plant nutrient availability and metal toxicity. Tardy (1997) calculated that laterites account for about one-third of the Earth's continental land area. India has vast stretches of land (0.246 M km^2) under the category of laterite and lateritic soils spread across diverse agro-ecological

Abbreviations: SWE, seaweed extract; RRF, recommended rate of fertilizers; DAT, days after transplanting; MOP, muriate of potash; SSP, single super phosphate; KSWE, *Kappaphycus* seaweed extract; GSWE, *Gracilaria* seaweed extract; INR, Indian Rupees; t, Tonne.

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regions. Laterite soils in India are predominantly found in the states of Odisha, Kerala, Maharashtra and in some parts of Andhra Pradesh, Tamil Nadu, Karnataka, Meghalaya and Western part of West Bengal. To overcome the constraints posed by these soils, relatively higher use of fertilizer is required to realize optimum yield as compared to the favourable soil types. However, excessive use of inorganic inputs towards raising crop productivity has severe detrimental effects on the environment (Tilman, 1999). It is well known that rice production contributes to the bulk (55%) of the agricultural greenhouse gas emissions in the world (Alam et al., 2016). Further, Yan et al. (2015) have reported that use of synthetic fertilizers account for approximately 50% of the total carbon foot print during rice production. The strategies to improve productivity should be ideally using inputs and techniques not only with low carbon footprint but also with the potential to reduce and mitigate various environmental impacts on account of rice production. In this context, seaweed based biostimulants are a greener alternative towards sustainably increasing crop yields (Ghosh et al., 2015). Unlike the traditional organic inputs employed in rice production which usually result in increased environmental impacts, at least in the short term (Hokazono and Hayashi, 2012), these biostimulants are unique wherein stable yield improvements are observed when used along with conventional fertilizers.

Kappaphycus alvarezii and *Gracilaria edulis* are two important tropical seaweeds whose cultivation technology has been developed in India. The extracts obtained from these seaweeds contain plant growth regulators, macro-, micro-nutrients as well as quaternary ammonium compounds. They have been reported to enhance productivity in many crops such as soybean (Rathore et al., 2009); in wheat (Zodape et al., 2009); rice (Pramanick et al., 2014a); rice-potato-green gram cropping system (Pramanick et al., 2014b) and in maize (Singh et al., 2016). This extract is being used extensively in other continents also (Ghosh et al., 2015). Life cycle assessment is a tool to quantitatively measure and establish the basis of sustainability and identify the processes that contribute to greater impacts and help in mitigating them. Recently, we reported the sustainability of use of these SWEs in maize (Singh et al., 2016). The present study was undertaken to test our hypothesis that the use of SWEs can sustainably bring about incremental yield advantage over and above the recommended rates of fertilizers in rice system and also to test whether there is scope to reduce the chemical fertilizer inputs without compromising the yield advantage, which has been hitherto not carried out. The investigation also sought to quantify the changes in environmental impacts by this intervention using life cycle impact assessment.

2. Materials and methods

2.1. Experimental site, design and treatments

A field experiment was conducted on rice in the red and lateritic soil of West Bengal, India, during the *kharif* season (July to November) of 2012 and 2013, consecutively, at the research farm of Institute of Agriculture, Visva-Bharati, Sriniketan, Birbhum, West Bengal which is located at 23° 40.167′ N and 87° 39.492′ E. The variety of rice used in the experiment was Swarna (MTU 7029). The altitude was 58.9 m above mean sea level and the area falls under sub-humid, sub-tropical belt of West Bengal. The soil was moderately acidic with pH of 5.5 and it was low in available nitrogen (137.6 kg ha^{-1}) and potassium (124.7 kg ha^{-1}), while it was medium in phosphorus (15.4 kg ha^{-1}). The experiment was conducted in Randomized Complete Block Design (RCBD) having thirteen treatment combinations consisting of full or half dose of recommended rate of fertilizers (RRF) and SWEs applied as foliar spray at different concentrations (v/v) as per treatments. The treatments were replicated thrice. The net plot size was 5 m × 3 m in which the plants were transplanted at a spacing of 20 cm × 15 cm. The RRF was 80: 40: 40 N: P_2O_5: K_2O kg ha^{-1} applied manually through urea, single superphosphate (SSP) and muriate of potash (MOP). The SWEs of *Kappaphycus* (KSWE) and *Gracilaria* (GSWE) were foliar sprayed as per treatments at 25, 50, and 70 d after transplanting (DAT) of rice. The spray volume was 600 L ha^{-1} for each spray. The water spray in the control plot was also done on the same days with the same amount of spray volume. Adjuvant (additive surfactant) was mixed in the tanks before spraying. The treatments are shown in Table 1.

2.2. Preparation of seaweed extract and its composition

The KSWE and GSWE were prepared as described earlier by us in Singh et al. (2016) and the extract used in the present experiment also belonged to the same batch as described earlier. The liquid filtrates obtained as per the method were considered as 100% concentration from which appropriate dilutions were prepared as per the treatments. The KSWE principally contained indole acetic acid, zeatin, choline, glycine betaine and potassium at a concentration of 27, 20, 57, 79, 33,654 mg L^{-1}, respectively, while the corresponding values in GSWE were 8.7, 3.1, 36, 63 and 682 mg L^{-1}, respectively. Apart from this gibberellic acid (GA_3) at 24 mg L^{-1} was present only in KSWE. The SWE also contained macro- and micronutrients in variable amounts (Singh et al., 2016).

2.3. Farm operations, data collection and analysis

Hand weeding was done at different times as per requirement. Herbicides were not applied in the experimental plot. One pretransplanting irrigation was applied for puddling followed by four irrigations at tillering (branching) (30 DAT), panicle (inflorescence) initiation (PI) (60–70 DAT), flowering (90–100 DAT) and at milking (110 DAT) stages.

Randomly five hills per plot were selected and tagged for taking biometric observations on yield components and yield at harvest. The number of panicles per 1 m^2 were counted (at harvest). Ten panicles were selected randomly from the five tagged hills and then grains were separated and counted. The mean value was expressed as number of grains per panicle. One thousand grains were counted for each treatment and their mass were recorded as test weight and expressed in g. After harvesting and threshing of rice, both seeds and straw of individual plots were sun dried. Grains were separated from the rice plants in each plot and expressed in t ha^{-1}. Similarly, straw from each net plot was taken after complete drying in the

Table 1
Various treatments tested to evaluate the efficacy of the foliar application of seaweed extracts on the rice productivity. KSWE - *Kappaphycus* seaweed extract; GSWE - *Gracilaria* seaweed extract; RRF - recommended rate of fertilizers.

Treatments	Label
Water spray + 100% RRF (Control)	T1
2.5% KSWE + 100% RRF	T2
5% KSWE + 100% RRF	T3
7.5% KSWE + 100% RRF	T4
10% KSWE + 100% RRF	T5
15% KSWE + 100% RRF	T6
2.5% GSWE + 100% RRF	T7
5% GSWE + 100% RRF	T8
7.5% GSWE + 100% RRF	T9
10% GSWE + 100% RRF	T10
15% GSWE + 100% RRF	T11
7.5% KSWE + 50% RRF	T12
7.5% GSWE + 50% RRF	T13