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Research Article

Optimising Foliar Feeding Rate of Seaweed Based Biostimulant (Crop Plus) For Transplant Aman Rice Varieties

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Abstract

Seaweed extract-based biostimulants are gaining increasing attention in modern agriculture for their ability to stimulate physiological processes, growth and productivity of crops without any environmental pollution. In many cases, indiscriminate application of seaweed extract leads to inconsistent results and reduced economic return. But seaweed extract is yet to be explored for increased rice productivity under Bangladesh conditions. To recognize the most suitable application rate of seaweed extract for transplant Aman rice, a field experiment was conducted at the Bangladesh Agricultural University following a randomized complete block design with three replications comprising two rice varieties namely, BRRI dhan75 and BRRI dhan87 and five application rates of seaweed based biostimulant 'Crop Plus' such as no Crop Plus (control), 300 mL ha^{-1}, 400 mL ha^{-1}, 500 mL ha^{-1} and 600 mL ha^{-1}. Foliar application of Crop Plus at different growth rates significantly enhanced the growth and yield performance of T. Aman rice. The variety BRRI dhan87 consistently outperformed BRRI dhan75 in most growth, yield attributes and yield, but BRRI dhan75 was more responsive to Crop Plus. Although applying Crop Plus @ >400 mL ha^{-1} did not result in additional yield advantages, economic returns increased progressively up to the highest application rate of 600 mL ha^{-1}. Based on the economic analysis, the application of Crop Plus at 600 mL ha^{-1} in two splits at 40 and 60 days after transplanting is recommended for T. Aman rice. Although BRRI dhan75 showed greater responsiveness to Crop Plus, BRRI dhan87 may be preferred for cultivation due to its higher productivity.

Introduction

Rice (*Oryza sativa*) plays an important role in alleviating poverty and malnutrition (Barah and Pandey, 2005) providing a means of livelihood to millions of people. The rice-based agricultural system has a tremendous influence on the agrarian economy of Bangladesh and contributes approximately 11.55% to the country's gross domestic product (GDP) from agriculture (BBS, 2024). Population in Bangladesh are increasing day by day, and the total population is projected to rise to around 238 million by the year 2050. This anticipated demographic surge will place immense pressure on the agricultural sector, necessitating a substantial increase in overall rice production to meet the future demand for food and sustain nutritional security for generations to come. The nation produced around 41.0 million MT of rice in FY 2023–24 from approximately 11.77 million hectares of land (BBS, 2024). But due to a range of factors, sustainable rice production in Bangladesh is facing various increasing challenges viz. yield stagnation, rising input costs, declining soil fertility and productivity, labor shortages and growing environmental degradation (Biswas *et al.,* 2019). Another major concern is, farmers are dependent on excessive use of chemical fertilizers and synthetic agro-inputs. Though these inputs can provide short-term yield gains, their prolonged application deplete soil organic matter, degrade soil structure, reduce beneficial microbial organisms and contribute to both greenhouse gas emissions and groundwater contamination (Ali *et al*., 2021).

To alleviate these concerns, the adoption of environmentally friendly and sustainable nutrient management practices may be a key priority for

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modern rice farming. One promising solution can be the use of seaweed extract, a natural bio-stimulant, containing growth-promoting substances such as auxins, gibberellins, cytokinins, betaines, polysaccharides, enzymes, amino acids and micronutrients like Fe, Zn, Mn, and Cu, which enhance plant vigor and nutrient use efficiency (Craigie, 2011). Seaweeds not just stimulates root development and plant vigor, also improves nutrient assimilation and stress tolerance, ultimately leading to better crop performance without affecting environmental stability (Khan *et al*., 2009; Craigie, 2011). From (Craigie, 2011), seaweed enhance plant metabolism, nutrient uptake, root development and resilience against biotic and abiotic stresses, thereby improving overall crop performance and yield. In Bangladesh, a seaweed extract based commercial product namely *Crop Plus* is available in the market. This formulation contains 18% seaweed extract and 2% alginic acid, offering a natural, eco-friendly approach for enhancing crop growth and maintaining soil health. Some researchers found that, application of Crop Plus has positive effects on seed germination, seedling vigor, and early growth of winter rice (Akter et al., 2026). Seaweed-based products are gaining popularity worldwide for their long-term benefit and compatibility with organic and sustainable farming systems (Shah *et al*., 2013; Layek *et al*., 2018). Seaweed extracts from tropical waters can also reduce urea fertilizer requirements in rice while improving growth and yield (Sunarpi et al., 2011). Moreover, these extracts promote root and shoot biomass and increase chlorophyll content in tomato and eggplant seedlings, thereby improving photosynthetic efficiency (Villa e Vila et al., 2024). They can also improve soil microbial activity, antioxidant responses and NPK uptake during tillering, leading enhanced yield and grain quality (Khan et al., 2009). Despite its considerable potential to enhance rice productivity, the application of seaweed extract-based biostimulants under Bangladesh conditions has received limited attention from researchers. Consequently, the optimum foliar application rate of seaweed extract for achieving higher rice productivity and maximizing economic returns remains largely unknown.

Keeping this knowledge gap in view, an experiment was conducted to optimize the foliar application rate of a seaweed-based biostimulant for T. Aman rice, and to study the comparative growth and yield responses of two T. aman rice varieties to seaweed extract based biostimulant application.

Materials and Methods

Experimental sie and Soil

The experiment was conducted at the Agronomy Field Laboratory of Bangladesh Agricultural University (BAU) during the Aman season, spanning from June to October 2023. The region was in the Old Brahmaputra Floodplain, Agro-ecological Zone-9 (18 meters above sea level with latitudes 24.75°N and longitudes 90.50°E) belonging to the Sonatola soil series and was a medium-high land with silt loam texture. The floodplain soil is dark-grey and non-calcareous, a pH of 6.5, suitable for most of the agricultural crops with low organic matter content (1.30%), indicating poor fertility. Soil possess total N content 0.10%, available P 27 ppm, available K 0.12 me/100g soil, Zn and S content are 0.52, 22.7 ppm, respectively. The ecological and geographical features make the area well-suited for rice cultivation, particularly during the *Aman* season.

The experimental site experienced a humid climate with substantial rainfall during the months of June to October, while the rest of the year was characterized by moderately moist to dry conditions. During the early part of the experiment, specifically in June and July, air temperatures were averaging between 30°C and 35°C. Relative humidity were ranging from 93.9% to 97.1%. Monthly sunshine varied from 230.5 to 120.95 hours between October and June. The crop received > 700 mm rainfall during the whole growing period.

Description of the Materials Used

Plant materials

Two high yielding T. Aman rice varieties namely BRRI dhan75 (short duration approximately 105 days) and BRRI dhan87 (long duration approximately 127 days) of Aman variety developed by the Bangladesh Rice Research Institute (BRRI) were used as test crops in this experiment. BRRI dhan75 has yield potential of over 5 t/ha and BRRI dhan87 can yield up to 6.5 t/ha.

Biostimulant

Crop Plus, a liquid seaweed-based biostimulant manufactured by Haychem Bangladesh Ltd., designed to supplement plant nutrition and promote plant growth through foliar application was used in this study. Chemical composition of Crop Plus are seaweed extract: 18%; alginic acid $[(C_6H_8O_6)n]$: 2%; total nitrogen: 8%; potash: 4%; phosphate: 2%; Fe: 1.56%; Mn:1.56%; Mg: 1% and other trace elements.

Experimental Design and Treatments

The experiment comprised two factors: Factor A included two T. Aman rice varieties namely, BRRI dhan75 and BRRI dhan87; Factor B included five application rates of Crop Plus such as No Crop Plus (control), Crop Plus @300 mL ha^{-1}, Crop Plus @400 mL ha^{-1}, Crop Plus @500 mL ha^{-1} and Crop Plus @ 600 mL ha^{-1}. Crop Plus was foliar sprayed as per treatment at 40 and 60 days after transplanting (DAT) of rice seedlings. The experimental layout followed a randomized complete block design (RCBD) with three replications. A total of 30-unit plots were established by randomly assigning 10 treatment combinations within each of the three blocks. Each unit plot was of size 10 m^2 (4 m × 2.5 m). A spacing of 0.5 m between plots and 1.0 m between blocks were maintained. The spray volume was 500 L ha^{-1}. For each unit plot the spray volume used was 0.5 L. For preparing the spray solution 6 or 8 or 10 or 12 mL Crop plus was mixed with 10 L of water as per treatment.

Crop Husbandry

The field was ploughed thoroughly using a power tiller, followed by puddling to create a suitable condition for rice transplanting. During the final stage of land preparation, the experimental plots received a basal application of fertilizers, including muriate of potash (105 kg ha^{-1}), triple super phosphate (60 kg ha^{-1}), gypsum (67 kg ha^{-1}) and zinc sulphate (10 kg ha^{-1}) to ensure balanced nutrient availability from the beginning of the crop cycle. Urea was applied at a total rate of 260 kg ha^{-1} top-dressed equally in three splits at 10, 30 and 50 days after transplanting (DAT) to support the crop's nitrogen requirements. On 25 June 2023, the pre-germinated seeds were sown on well-prepared, moist nursery beds. Thirty-day-old seedlings were uprooted and transplanted on 25 July 2023 with three seedlings per hill in well-puddled experimental plots. A spacing of 25 cm × 15 cm was maintained for both the rice varieties. Weeds were controlled through manual weeding thrice at 10, 30, and 50 DAT**.** Due to abundant rainfall in the growing season, the crop was mostly grown as a rainfed one. Only a single supplemental irrigation was provided during the flowering stage to maintain adequate soil moisture and support optimal crop performance during this critical growth phase. The field remained largely free from significant insect pests and diseases throughout the growing period, so no pest or disease control interventions were necessary.

Sampling and Data Collection

Plant height and tillering ability were recorded from five randomly selected hills at 45 and 60 DAT and at harvest. For sampling, prior to harvest, five hills were randomly chosen from each plot, excluding those along the borders and uprooted to gather data on different yield parameters. Harvesting was done when 80% of the seeds became golden-yellow in color. Grain and straw yields were calculated from harvesting central 1 m^2 area of each unit plot. Grain yield was recorded at 14% moisture content after sun drying. Ultimately, the grain and straw yields were converted into tons per hectare.

Economic Analysis

Economic analysis was performed to determine the profitability of different treatments. Labor wages, price of different inputs and products were calculated based on local rate/market price. Total variable cost, gross return, gross margin and benefit cost ratio (Gross return/Total cost) were calculated.

Statistical Analysis

The collected data were organized and tabulated for statistical analysis. Analysis of variance (ANOVA) was performed using the statistical software package MSTAT. Differences among treatment means were evaluated using Duncan's Multiple Range Test (DMRT).

Results

Growth parameters

Effect of variety on plant height

Results revealed that plant height of T. Aman rice was significantly affected by variety at 45, 60 DAT and at harvesting. BRRI dhan87 produced taller plants compared to BRRI dhan75 at all the sampling dates (Table 1).

Effect of application rate of Crop Plus on plant height

Application of Crop Plus significantly increased plant height at harvest but had no effect at 45 and 60 DAT. At 45 DAT, plant heights ranged from 92.88 cm (400 mL ha^{-1}) to 93.70 cm (600 mL ha^{-1}), with the control at 92.97 cm; at 60 DAT, values varied from 104.32 cm (control) to 107.60 cm (600 mL ha^{-1}), both non-significant. At harvest, 600 mL ha^{-1} produced the tallest plants (114.02 cm), followed by 500 mL ha^{-1} (113.40 cm) and 400 mL ha^{-1} (112.62 cm), all significantly taller than 300 mL ha^{-1} (112.00 cm) and the control (111.22 cm) (Table 1).

Table 1. Effect of variety and application rate of Crop Plus on plant height of T. *Aman* rice at different days after transplanting.

Variety	Plant height (cm) at different days after transplanting (DAT)		
	45	60	At harvest
BRRI dhan75	87.92b	98.42b	105.94b
BRRI dhan87	98.69a	113.92a	119.40a
$S\bar{x}$	1.30	1.53	0.33
Level of significance	**	**	**
CV (%)	3.81	3.97	0.79
Application rate of Crop Plus			
No Crop plus	92.97	104.32	111.22c
Crop plus at 300 mL ha^{-1}	93.42	105.47	112.00bc
Crop plus at 400 mL ha^{-1}	92.88	106.40	112.62ab
Crop plus at 500 mL ha^{-1}	93.55	107.07	113.40ab
Crop plus at 600 mL ha^{-1}	93.70	107.60	114.02a
$S\bar{x}$	2.05	2.43	0.51
Level of significance	NS	NS	**
CV (%)	3.81	3.97	0.79

** =Significant at 1% level of probability, NS = Not significant. In a column, figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Effect of interaction between variety and application rate of Crop Plus on plant height

The interaction of variety and Crop Plus rate significantly influenced plant height at 45 and 60 DAT ($p < 0.05$) and at harvest ($p < 0.01$). At 45 DAT, heights ranged from 87.30 cm (BRRI dhan75, No Crop Plus) to 99.36 cm (BRRI dhan87, Crop plus at 300 mL ha^{-1}), with BRRI dhan87 generally taller than BRRI dhan75 for any Crop Plus rate. At 60 DAT, values varied from 97.17 cm (BRRI dhan75, No Crop Plus) to 115.40 cm (BRRI dhan87, Crop plus at 600 mL ha^{-1}), showing consistent height gains with higher Crop Plus rates in both varieties. At harvest, (BRRI dhan87, Crop plus at 600 mL $ha^{-1)}$ recorded the maximum height (121.00 cm), statistically similar to other treatments for BRRI dhan87 except (BRRI dhan87, No Crop Plus) and significantly taller than all combinations for BRRI dhan75. The shortest plants were found in (BRRI dhan75, No Crop Plus) 104.63 cm (Table 2).

Table 2. Interactions of variety and application rate of Crop Plus on plant height at different days after transplanting.

Interactions		Plant height (cm) at different days after transplanting (DAT)		
		45	60	At harvest
BRRI dhan75	No Crop plus	87.30 d	97.17c	104.63 c
	Crop plus at 300 mL ha^{-1}	87.46 d	97.37c	105.50 c
	Crop plus at 400 mL ha^{-1}	88.10 d	98.47c	105.60 c
	Crop plus at 500 mL ha^{-1}	88.60 bcd	99.30bc	106.73 c
	Crop plus at 600 mL ha^{-1}	88.13 cd	99.80bc	107.03 c
BRRI dhan87	No Crop plus	98.63ab	111.47ab	117.80 b
	Crop plus at 300 mL ha^{-1}	99.36a	113.57a	118.50ab
	Crop plus at 400 mL ha^{-1}	97.66abcd	114.33a	119.63ab
	Crop plus at 500 mL ha^{-1}	98.50abc	114.83a	120.07ab
	Crop plus at 600 mL ha^{-1}	99.26a	115.40a	121.00a
$S\bar{x}$		2.89	3.43	0.73
Level of significance		*	*	**
CV (%)		3.81	3.97	0.79

** =Significant at 1% level of probability, NS = Not significant. In a column, figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Effect of variety on tillering ability

Variety had a significant effect at 45 DAT and at harvest ($p < 0.01$) but not at 60 DAT. At 45 DAT, BRRI dhan87 produced more tillers (10.23) than BRRI dhan75 (9.23). At 60 DAT, tiller numbers were statistically similar between varieties, averaging 12.38 for BRRI dhan75 and 13.43 for BRRI dhan87. At harvest, BRRI dhan87 again recorded a higher number of tillers $hill^{-1}$ (13.06) compared to BRRI dhan75 (12.28). (Table 3).

Effect of application rate of Crop Plus on tillering ability

Application rate of Crop Plus significantly affected tiller number at 45 DAT and at harvest ($p < 0.01$) but not at 60 DAT. At 45 DAT, tillers ranged from 8.86 in the control (No Crop Plus) to 10.71 in 600 mL ha^{-1} Crop Plus, with 600 mL ha^{-1} producing significantly more tillers than the control and 300 mL ha^{-1}. At harvest, the highest tiller numbers were recorded in 600 mL ha^{-1} (13.73), 500 mL ha^{-1} (13.53), and 400 mL ha^{-1} (13.35), which were statistically similar and significantly higher than at 300 mL ha^{-1} (11.66) and the control (11.06). At 60 DAT, tiller numbers varied from 11.85 (No Crop plus) to 14.07 (600 mL ha^{-1}), but differences were non-significant (Table 3).

Table 3. Effect of variety and application rate of Crop Plus on total tillers hill $^{-1}$ at different days after transplanting.

Variety	Total tillers hill^{-1} at different days after transplanting (DAT)		
	45	60	At harvest
BRRI dhan75	9.23b	12.38	12.28b
BRRI dhan87	10.23a	13.43	13.06a
$S\bar{x}$	0.37	0.53	0.09
Level of significance	**	NS	**
CV (%)	10.38	11.38	1.94
Application rate of Crop Plus			
No Crop plus	8.86b	11.85	11.06 c
Crop plus at 300 mL ha^{-1}	8.90b	12.07	11.66 b
Crop plus at 400 mL ha^{-1}	9.81ab	12.93	13.35a
Crop plus at 500 mL ha^{-1}	10.36ab	13.60	13.53a
Crop plus at 600 mL ha^{-1}	10.71a	14.07	13.73a
$S\bar{x}$	0.58	0.85	0.14
Level of significance	**	NS	**
CV (%)	10.38	11.38	1.94

** =Significant at 1% level of probability, NS = Not-significant. In a column, figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Effect of interaction between variety and application schedule of Crop Plus on tillering ability

The interaction between variety and Crop Plus treatment was non-significant at 45 and 60 DAT but became significant at harvest ($p < 0.05$). At harvest, total tiller number ranged from 10.86 in (BRRI dhan75, no Crop Plus) to 14.20 in (BRRI dhan87, 600 mL ha^{-1} Crop Plus). Across all treatments, BRRI dhan87 consistently produced more tillers than BRRI dhan75, indicating a genetic advantage in tillering capacity. The highest tiller counts were recorded at the 600 mL ha^{-1} Crop Plus application rate in both varieties, significantly surpassing the control and lower doses. This suggests that increased Crop Plus application enhances tiller production, particularly in the more responsive BRRI dhan87 (Table 4).

Table 4. Interactions of variety and application rate of Crop Plus on total tillers hill^{-1} at different days after transplanting

Interactions		Total tillers hill^{-1} at different days after transplanting (DAT)		
		45	60	At harvest
BRRI dhan75	No Crop plus	8.53	11.57	10.86 f
	Crop plus at 300 mL ha^{-1}	8.50	11.70	11.26 f
	Crop plus at 400 mL ha^{-1}	9.07	12.03	12.86 d
	Crop plus at 500 mL ha^{-1}	9.77	13.00	13.13 cd
	Crop plus at 600 mL ha^{-1}	10.30	13.60	13.26 bcd
BRRI dhan87	No Crop plus	9.20	12.13	11.26 f
	Crop plus at 300 mL ha^{-1}	9.30	12.43	12.06 e
	Crop plus at 400 mL ha^{-1}	10.57	13.83	13.83abc
	Crop plus at 500 mL ha^{-1}	10.97	14.20	13.93ab
	Crop plus at 600 mL ha^{-1}	11.13	14.53	14.20a
$S\bar{x}$		0.83	1.20	0.20
Level of significance		NS	NS	*
CV (%)		10.38	11.38	1.94

* =Significant at 5% level of probability, NS = Not-Significant. In a column, figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Yield Contributing attributes and Yield of T. Aman rice

Number of effective tillers hill^{-1}

Variety had a highly significant influence ($p < 0.01$) on effective tiller production. BRRI dhan87 produced the higher number of effective tillers hill^{-1} (12.13), which was 9.18% greater than BRRI dhan75 (11.11). This advantage in BRRI dhan87 may be attributed to its stronger tillering ability and better nutrient utilization efficiency, enabling it to support more productive tillers. The higher number of effective tillers directly contributes to the potential panicle number per unit area, thereby influencing final grain yield (Table 5).

The number of effective tillers per hill varied significantly among treatments ($p < 0.01$). The lowest number of effective tillers (9.60) was recorded in (control, no Crop Plus), while the highest (13.25) was in (600 mL ha^{-1} Crop Plus). There was a progressive increase in effective tillers with higher Crop Plus application rates, indicating that growth regulator supplementation enhanced tillering capacity and survival of productive tillers (Table 5).

The number of effective tillers varied significantly ($p < 0.01$) among interactions. The highest number of effective tillers was recorded 14.20 at (BRRI dhan87, 600 mL ha^{-1} Crop Plus), followed by 12.87 at (BRRI dhan87, 400 mL ha^{-1} Crop Plus) and (BRRI dhan87, 500 mL ha^{-1} Crop Plus) (12.90), indicating that BRRI dhan87 generally produced more productive tillers. The lowest effective tillers were found at (BRRI dhan75, No Crop Plus) (9.33), showing that variety BRRI dhan75 had fewer tillers under the first treatment. Overall, BRRI dhan87 performed better than BRRI dhan75 in producing effective tillers and treatment 600 mL ha^{-1} Crop Plus (with BRRI dhan87) was the most effective (Table 6).

Number of non-effective tiller hill^{-1}

Differences between varieties were statistically non-significant, although BRRI dhan75 (1.17) produced slightly more non-effective tillers than BRRI dhan87 (0.93). The slightly lower non-effective tiller counted in BRRI dhan87 suggests more efficient tiller survival and conversion into productive panicles. This could be due to better assimilate partitioning and improved spikelet fertility (Table 5).

Non-effective tillers were also significantly influenced by treatments ($p < 0.01$). The highest number (1.46) was observed in No Crop Plus, while the lowest (0.48) was at 600 mL ha^{-1} Crop Plus. This trend suggests that Crop Plus application reduced the proportion of sterile or unproductive tillers, thereby improving yield potential (Table 5).

Non-effective tillers were significantly different ($p < 0.05$) among interactions. The highest non-effective tiller count was observed 1.53 at (BRRI dhan75, No Crop Plus) and 1.40 at (BRRI dhan87, No Crop Plus), suggesting some treatments led to more unproductive tillers. The lowest value (0.00) was recorded at (BRRI dhan87, 600 mL ha^{-1} Crop Plus), indicating that all the tillers in this interaction were productive. This shows that appropriate treatment (600 mL ha^{-1} Crop Plus) can minimize unproductive tillers, especially in high-yielding varieties (Table 6).

Number of grains panicle^{-1}

Varietal differences were highly significant ($p < 0.01$). BRRI dhan87 had a markedly higher grain number per panicle (117.12) compared to BRRI dhan75 (101.15), an increase of 15.78%. The superiority of BRRI dhan87 in this trait may be linked to a greater number of spikelets per panicle combined with efficient grain filling, both of which enhance sink capacity and yield potential (Table 5).

The number of filled grains per panicle was significantly affected by treatments ($p < 0.01$). The lowest value (103.02) was recorded at No Crop Plus, whereas the highest (112.17) was observed at (300 mL ha^{-1} Crop Plus). Treatments 500 mL ha^{-1} and 600 mL ha^{-1} Crop Plus also produced high grain counts, indicating that moderate to high doses of Crop Plus enhanced grain filling efficiency (Table 5).

The number of grains per panicle was highly significant ($p < 0.05$) among interactions. Maximum grains per panicle were recorded at BRRI dhan87 with 400 mL ha^{-1}, 500 mL ha^{-1} and 600 mL ha^{-1} Crop Plus and (all ~119.6), followed closely by (BRRI dhan87, 300 mL ha^{-1}) (117.67). The lowest grain number was in (BRRI dhan75, No Crop Plus) (96.73), showing a large difference between varieties. BRRI dhan87 generally outperformed BRRI dhan75 and treatments 400 mL ha^{-1} to 600 mL ha^{-1} Crop Plus in BRRI dhan87 gave the best results (Table 6).

Number of sterile spikelets panicle^{-1}

The varietal difference was significant ($p < 0.05$). BRRI dhan87 recorded a higher number of sterile spikelets per panicle (15.29) compared to BRRI dhan75 (12.99). While higher sterility might reduce the proportion of fertile grains, in this case it was likely a consequence of BRRI dhan87’s higher total spikelet number, which can sometimes increase competition among spikelets for assimilates during grain filling (Table 5).

Sterile spikelets varied significantly among treatments **(**$p < 0.05$**).** The highest sterility (17.20 spikelets) occurred at No Crop Plus, while the lowest (12.66) was recorded at 600 mL ha^{-1} Crop Plus. This reduction in sterility with Crop Plus suggests improved pollination and grain set (Table 5).

Significant differences ($p < 0.05$) were noted for sterile spikelets among interactions. Highest sterility occurred at (BRRI dhan87, No Crop Plus) (19.23), followed by (BRRI dhan87, 600 mL ha^{-1}) (16.46), indicating that some high-tiller treatments also resulted in more unfilled grains. The lowest sterility was recorded at (BRRI dhan75, 600 mL ha^{-1}) (11.76). Reducing spikelet sterility appears crucial for increasing final grain yield and BRRI dhan75 tended to have fewer sterile spikelets than BRRI dhan87 (Table 6).

1000-grain weight

A significant varietal difference ($p < 0.01$) was observed, with BRRI dhan87 producing heavier grains (23.25 g) than BRRI dhan75 (20.45 g). The heavier grains in BRRI dhan87 indicate better grain filling and possibly denser endosperm development, which are critical determinants of yield and grain quality (Table 5).

The 1000-grain weight was also not significantly affected by treatments (NS), with values ranging from 21.45 g (No Crop Plus) to 22.07 g (500 mL ha^{-1}and 600 mL ha^{-1}). This suggests that Crop Plus improved yield primarily through tiller and grain number rather than grain size (Table 5).

Highly significant differences ($p < 0.05$) were found among interactions. The heaviest 1000-grain weight was observed at (BRRI dhan87, 600 mL ha^{-1}) (23.50 g) and (BRRI dhan87, 500 mL ha^{-1}) (23.46 g), followed closely by (BRRI dhan87, 400 mL ha^{-1}) (23.36 g). The lowest weights were recorded in BRRI dhan75 treatments (20.06–20.66 g). This suggests that BRRI dhan87 grains were larger and heavier than BRRI dhan75 across treatments (Table 6).

Grain Yield

The difference in grain yield between varieties was highly significant ($p < 0.01$). BRRI dhan87 yielded 5.38 t ha^{-1}, which was 26.89% higher than BRRI dhan75 (4.24 t ha^{-1}). This improvement in BRRI dhan87 can be explained by its higher effective tiller number, more grains per panicle, greater total spikelet number, and heavier 1000-grain weight (Table 5).

Grain yield differed significantly ($p < 0.01$) by the treatments. The lowest yield (4.41 t ha^{-1}) was recorded in No Crop Plus, while the highest (5.06 t ha^{-1}) was observed at 600 mL ha^{-1}. Yield improvements followed the trend of increased effective tillers and reduced sterility with higher Crop Plus application rates (Table 5).

Very significant differences were observed among the interactions. Highest yield was produced by (BRRI dhan87, 600 mL ha^{-1}) (5.63 t ha^{-1}), closely followed by (BRRI dhan87, 400 mL ha^{-1}) and (BRRI dhan87, 500 mL ha^{-1}) (5.53 t ha^{-1}). The lowest yield was at (BRRI dhan75, No Crop Plus) (3.85 t ha^{-1}). BRRI dhan87 consistently outperformed BRRI dhan75, with 600 mL ha^{-1} giving maximum yield (Table 6).

Due to application of Crop Plus, rice grain yield increase over control ranged from 7.01 to 16.62 % in BRRI dhan75 and 5.23 to 13.28% in BRRI dhan87 (Figures 1 and 2) which confirms that BRRI dhan75 is more responsive to Crop Plus compared to BRRI dhan87.

Straw yield

A highly significant varietal difference ($p < 0.01$) was found, with BRRI dhan87 producing more straw (5.93 t ha^{-1}) than BRRI dhan75 (4.74 t ha^{-1}). This suggests that BRRI dhan87 has greater vegetative growth and biomass accumulation, which may also contribute to higher assimilate availability during grain filling (Table 5).

Straw yield did not differ significantly (NS) among the treatments, ranging from 4.90 t ha^{-1} at No Crop Plus to 5.59 t ha^{-1} at 600 mL ha^{-1} Crop Plus. However, there was a general increasing trend with higher Crop Plus doses, reflecting better vegetative growth (Table 5).

Significant differences ($p < 0.01$) were found among the interactions. Highest straw yield was found at (BRRI dhan87, 400 mL ha^{-1}) and (BRRI dhan87, 600 mL ha^{-1}) (6.18 t ha^{-1}), indicating that these treatments also boosted vegetative biomass. Lowest straw yield was found at (BRRI dhan75, No Crop Plus) (4.39 t ha^{-1}). Higher straw yield often coincided with higher grain yield in BRRI dhan87 (Table 6).

Harvest index

A significant varietal difference ($p < 0.05$) was recorded for harvest index. BRRI dhan87 had a slightly higher HI (47.56%) compared to BRRI dhan75 (47.14%), suggesting that BRRI dhan87 was marginally more efficient at partitioning total biomass into economic yield. While the numerical difference is small, it complements the overall higher productivity observed in BRRI dhan87 (Table 5).

Harvest index remained statistically non-significant (NS) among treatments, ranging from 47.07% (400 mL ha^{-1}) to 47.48% (600 mL ha^{-1}). This consistency suggests that while total biomass increased, the proportion of grain to total biomass remained relatively stable (Table 5).

Table 5. Effect of variety and application rate of Crop Plus on yield and yield contributing characters of T. *Aman* rice

Varieties	Effective tillers hill^{-1}	Non-effective tillers hill^{-1}	Grains panicle^{-1}	Sterile spikelets panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
BRRI dhan75	11.11b	1.17	101.15b	12.99b	20.45b	4.24b	4.74b	47.14b
BRRI dhan87	12.13a	0.93	117.12a	15.29a	23.25a	5.38a	5.93a	47.56a
$S\bar{x}$	0.06	0.14	0.46	0.91	0.30	0.02	0.18	0.17
Level of significance	**	NS	**	*	**	**	**	*
CV (%)	1.44	36.84	1.15	17.71	3.73	1.25	9.01	0.99
Application rate of Crop Plus								
No Crop plus	9.60d	1.46a	103.02 c	17.20a	21.45	4.41 d	4.90	47.32
Crop plus at 300 mL ha^{-1}	10.50 c	1.16a	109.12 b	15.10ab	21.75	4.68 c	5.18	47.43
Crop plus at 400 mL ha^{-1}	12.25 b	1.10ab	112.17a	12.90ab	21.93	4.93 b	5.54	47.07
Crop plus at 500 mL ha^{-1}	12.50 b	1.03ab	111.02ab	12.81b	22.07	4.95ab	5.49	47.45
Crop plus at 600 mL ha^{-1}	13.25a	0.48 b	111.25ab	12.66b	22.07	5.06a	5.59	47.48
$S\bar{x}$	0.10	0.22	0.72	1.45	0.47	0.03	0.28	0.27
Level of significance	**	**	**	*	NS	**	NS	NS
CV (%)	1.44	36.84	1.15	17.71	3.73	1.25	9.01	0.99

** =Significant at 1% level of probability, * = Significant at 5% level of probability NS = Not Significant. In a column, figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

No significant difference (NS) was found among interactions, meaning the ratio of grain yield to total biomass was fairly constant. Harvest index ranged between 46.71–47.93%, with the highest at (BRRI dhan87, No Crop Plus) (47.93%) and lowest at (BRRI dhan75, No Crop Plus) (46.71%). This indicates that yield improvements were mainly due to increases in total biomass rather than shifts in allocation efficiency (Table 6).

Table 6. Interactions of variety and application rate of Crop Plus on yield and yield contributing characters of T. *Aman* Rice

Interactions		Effective tillers hill^{-1}	Non-effective tillers hill^{-1}	Grains panicle^{-1}	Sterile spikelets panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
BRRI dhan75	No Crop plus	9.33 g	1.53a	96.73e	15.16ab	20.06c	3.85f	4.39 b	46.71
	Crop plus at 300 mL ha^{-1}	10.17 f	1.10ab	100.5d	13.73ab	20.40c	4.12e	4.59 b	47.30
	Crop plus at 400 mL ha^{-1}	11.63 d	1.23a	104.73c	12.23ab	20.50bc	4.33d	4.88ab	46.96
	Crop plus at 500 mL ha^{-1}	12.10 cd	1.03ab	102.60cd	12.03ab	20.66bc	4.38d	4.85ab	47.42
	Crop plus at 600 mL ha^{-1}	12.30 c	0.96ab	102.90cd	11.76 b	20.63bc	4.49d	5.00ab	47.32
BRRI dhan87	No Crop plus	9.87 f	1.40a	109.30 b	19.23a	22.83ab	4.97c	5.40ab	47.93
	Crop plus at 300 mL ha^{-1}	10.83 e	1.23a	117.67a	16.46ab	23.10a	5.23b	5.77ab	47.55
	Crop plus at 400 mL ha^{-1}	12.87 b	0.96ab	119.60a	13.56ab	23.36a	5.53a	6.18a	47.18
	Crop plus at 500 mL ha^{-1}	12.90 b	1.03ab	119.43a	13.60ab	23.46a	5.53a	6.12a	47.49
	Crop plus at 600 mL ha^{-1}	14.20a	0.00 b	119.60a	13.56ab	23.50a	5.63a	6.18a	47.64
	$S\bar{x}$	0.14	0.32	1.02	2.04	0.67	0.05	0.39	0.38
	Level of significance	**	*	*	*	*	**	**	NS
	CV (%)	1.44	36.84	1.15	17.71	3.73	1.25	9.01	0.99

** =Significant at 1% level of probability, * =Significant at 5% level of probability NS = Not-Significant. In a column, figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT

Economic Performance

Table 7 reveals a consistent economic benefit associated with Crop Plus application across both rice varieties studied, as reflected in improved financial returns. The superior yield performance of BRRI dhan87 resulted in greater economic returns compared with BRRI dhan75. For BRRI dhan75, foliar application of Crop Plus at 600 mL ha^{-1} resulted in the highest net return (BDT 36,650 ha^{-1}) and BCR (1.36). In the case of BRRI dhan87, the highest net return (BDT 71,050 ha^{-1}) and BCR (1.70) were recorded when Crop Plus was applied as a foliar spray at 600 mL ha^{-1}. The No Crop Plus application resulted in the lowest net return and BCR in both varieties. Thus, results showed a gradual increase in monetary returns with increasing rates of Crop Plus application.

Table 7. Economic efficiency of rice varieties under different foliar feeding treatments of Crop Plus

Treatment		Variable Cost (BDT ha^{-1})	Seaweed Extract Cost (BDT ha^{-1})	Labor Cost for Spraying Seaweed Extract (BDT ha^{-1})	Total Variable Cost (BDT ha^{-1})	Gross Return (BDT ha^{-1})	Net Return (BDT ha^{-1})	Benefit Cost ratio (BCR)
BRRI dhan75	No Crop plus	98000	00	00	98000	118200	20200	1.20
	300 mL ha^{-1}	98000	600	1400	100000	125950	25950	1.26
	400 mL ha^{-1}	98000	800	1400	100200	132650	32450	1.32
	500 mL ha^{-1}	98000	1000	1400	100400	133750	33350	1.33
	600 mL ha^{-1}	98000	1200	1400	100600	137250	36650	1.36
BRRI dhan87	No Crop plus	98000	00	00	98000	151250	53250	1.54
	300 mL ha^{-1}	98000	600	1400	100000	159600	59600	1.59
	400 mL ha^{-1}	98000	800	1400	100200	169150	68950	1.69
	500 mL ha^{-1}	98000	1000	1400	100400	168850	68450	1.68
	600 mL ha^{-1}	98000	1200	1400	100600	171650	71050	1.70

Seaweed extract price= BDT 1000 L^{-1}; Wage of a labor = BDT 700 day^{-1}; Price of rice grain = BDT 25 kg^{-1}; Price of rice straw= BDT 5 kg^{-1}. 1US$- BDT 122 * Seaweed Extract was foliar sprayed @ 2 ml m^{-2} at nursery bed and @ 500 ml ha^{-1} at main field

Discussion

The results showed that BRRI dhan87 consistently produced taller plants than BRRI dhan75, which indicates a varietal advantage in vegetative growth. This difference in plant height could be associated with genotypic variations in growth potential as well as the physiological response to applied treatments such as seaweed-based biostimulants. Seaweed ingredients can efficiently increase nutrient uptake especially of nitrogen and potassium, which are responsible for vegetative growth and cell expansion (Ali *et al.,* 2016). Moreover, due to seaweed application photosynthetic efficiency and chlorophyll content also improved that contributes to greater biomass accumulation and plant height (Shukla *et al.,* 2021). However, gradual enhancement of nutrient uptake, stimulate cell elongation, and delay senescence take place because of auxins, cytokinins, gibberellins, and polysaccharides (Khan *et al*., 2009; Nabti *et al*., 2017). Higher application rates (500–600 mL ha⁻¹) amplify these effects, which leads to significantly increase taller plants (El-Safy *et al.,* 2025; Sharma *et al*., 2014). BRRI dhan87 shows greater height gains than BRRI dhan 75 especially at higher application rates due to influence of genetic potential for the interaction between variety and Crop Plus application rate. Similarly, variety and treatment interactions showed significantly taller plants in specific cultivars (Sebastian, 2021; Deb and Singh, 2022). Thus, the physiological and biochemical benefit of seaweed components seen in growth that determines by the variety. Genetic variation is responsiveness to growth stimuli and resource allocation which ensured from the significant difference in tiller number between BRRI dhan75 and BRRI dhan87 notably at 45 DAT and at harvest (Chen *et al.,* 2022). During the tillering stage seaweed extracts are known to enhance rhizosphere nutrient availability and microbial communities, contributing to increased tiller formation (Chen *et al*., 2022; Deepana *et al.,* 2021). In addition, seaweed treatments boost tiller number and productive tillers in paddy when combined with fertilizers (Deepana *et al*., 2021).

The application rate of Crop Plus significantly influenced tiller number, with the highest dose (600 mL ha^{-1}) producing more tillers than the control and lower doses at 45 DAT and at harvest, though differences were not significant at 60 DAT. Such responses align with findings that seaweed extracts enhance tillering by improving nutrient availability and rhizosphere microbial activity during tiller initiation (Banjare *et al*., 2025). The trend indicates that higher rates of biostimulant accelerate vegetative proliferation under favorable conditions (Sebastian, 2021).

The significant interaction between variety and Crop Plus application schedule at harvest showed that BRRI dhan 87 produced substantially more tillers under high application rates (e.g., 600 mL ha^{-1}) than BRRI dhan75**,** highlighting a genetic responsiveness to biostimulant timing and dose (Surma *et al.,* 2025). Research on rice in Tamil Nadu likewise found that seaweed extract application during early vegetative stages markedly increased productive tiller numbers, particularly in cultivars with high baseline tillering potential (Deepana *et al.,* 2021).

The application of the seaweed-based biostimulant Crop Plus significantly increased the number of effective tillers per hill. It indicates that the bioactive compounds in seaweed extracts stimulated bud initiation and enhanced the survival of tillers, resulting in a higher number of productive tillers per hill (Surma *et al.,* 2025). Moreover, it directly influenced the grain yield by contributing to a greater number of panicles per unit area.

Crop Plus also significantly reduced the number of non-effective tillers and sterile spikelets. Devi & Mani (2015) reported that foliar application of seaweed extract at 15% K-sap in combination with 100% recommended dose of fertilizers (RDF) significantly enhanced rice performance, resulting in higher growth and yield attributes, including increased number of productive tillers per hill, panicle length, test weight, grain yield and straw yield**.**

The 1000-grain weight was higher in treated plants, especially at higher doses, indicating improved grain filling and grain quality. The endosperm development and grain density increased due to the presence of amino acids, vitamins, and micronutrients in seaweed extracts (Craigie, 2011). BRRI dhan87 consistently outperformed BRRI dhan75, which shows that high-yielding varieties are more responsive to biostimulant treatments, possibly due to their greater genetic potential to utilize external inputs efficiently.

Although total spikelet numbers and harvest index were not significantly affected by treatments, the biological and grain yields increased notably under higher doses of Crop Plus. Seaweed extracts have been shown to boost shoot elongation, enhance photosynthesis by increasing chorophyll content and vegetative vigor that improve grain quality and nutrient density (Khan et al., 2009), which supports both vegetative and reproductive growth. Due to this reason the number of non-effective tillers and sterile spikelets also reduced.

Overall, the most superior results across all yield and yield-contributing traits are showed by the combination of BRRI dhan87 and the highest dose of Crop Plus. The data clearly indicate that the physiological responses triggered by seaweed extracts particularly enhanced nutrient assimilation, better tiller survival, and improved spikelet fertility were more effectively utilized by BRRI dhan87 than BRRI dhan75. This suggests a strong genotype × treatment interaction, where the genetic potential of BRRI dhan87 aligns well with the growth-promoting effects of Crop Plus. Increasing the Crop Plus application rate beyond 400 mL ha^{-1} did not result in any significant yield improvement. This must be due to the saturation effect that occurs when applying fertilizer or nutrients exceeds a crop's maximum physiological uptake capacity leads to stagnated or even reduced yield providing zero economic and/or agronomic benefit. In this stdy, no further yield improvement was observed when Crop Plus was applied at rates exceeding 400 mL ha^{-1}, but economic returns continued to increase gradually, reaching their maximum at the highest tested rate of 600 mL ha^{-1}.

In modern rice production, to boost the productivity selecting nutrient-responsive, high-yielding varieties and integrating them with biostimulant-based crop management strategies needs to be followed (Akter et al., 2026). Seaweed serves as an excellent growth promoter for crops and conditioners for soil without any problems caused to the environment. Seaweed extracts are non-toxic, non-polluting, biodegradable which are safer for the environment and human (Khan *et al.*, 2009). seaweed fertilizer improves soil health by enhancing water retention, developing microbial activity, and mitigating environmental problems such as water pollution and soil degradation (Nabti *et al.,* 2016). Crop Plus as a seaweed product, not only support plant vigor and reproductive efficiency but also contribute to sustainable farming by reducing dependency on synthetic inputs without causing any harm to the environment. Therefore, the findings of this study reinforce the potential of using seaweed-derived biostimulants in combination with suitable rice genotypes to achieve higher yield with better input efficiency under field conditions.

Conclusion

Present study confirmed that the seaweed-based biostimulant Crop Plus significantly boosted the growth and yield performance of T. Aman rice, achieving yield increases of more than 16% over control, highlighting its potential as a sustainable input for rice cultivation. The response of T. Aman rice to Crop Plus was dose-dependent, with varietal differences observed in the magnitude of response. Although no further yield improvement was observed when Crop Plus was applied at rates exceeding 400 mL ha^{-1}, economic returns continued to increase gradually, reaching their maximum at the highest tested rate of 600 mL ha^{-1}. Therefore, considering the economic performance, the application of the seaweed-based biostimulant Crop Plus at 600 mL ha^{-1}, applied twice at 40 and 60 days after transplanting, may be recommended for T. Aman rice cultivation. While BRRI dhan75 responded more positively to Crop Plus application than BRRI dhan87, BRRI dhan87 exhibited superior yield performance and therefore may be recommended for cultivation from a productivity standpoint.

These findings suggest that Crop Plus can serve as an excellent biostimulant for improving rice productivity, with varietal selection playing an important role in optimizing its benefits. Further multi-location and multi-season trials are suggested to validate the consistency of these responses before making any recommendations.

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