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Economics of Seaweed-Based Biostimulant Application in Soybean (*Glycine max* L.) under Inceptisol Conditions

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Abstract

The present investigation was undertaken to evaluate the economic implications of applying seaweed-based biostimulants, *Kappaphycus alvarezii* and *Ascophyllum nodosum*, on the cost of cultivation of soybean (*Glycine max* L.) cv. Phule Kimaya. The field experiment was conducted during the kharif season of 2024 at the Post Graduate Institute Research Farm, Department of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, on a medium-deep black soil belonging to the Inceptisol order. The experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. The treatments comprised foliar spray and soil drenching of *Kappaphycus alvarezii* and *Ascophyllum nodosum* applied individually and in combination, along with the recommended dose of fertilizers (RDF). The cost of cultivation for each treatment was estimated based on the prevailing market prices of inputs, labour and field operations. The results revealed that the lowest cost of cultivation (₹ 46,887 ha⁻¹) was recorded under the absolute control, whereas the highest cost (₹ 74,158 ha⁻¹) was observed with the combined foliar spray and soil drenching application of *Ascophyllum nodosum* (T₁₀), followed by the combined application of *Kappaphycus alvarezii* (T₆), which recorded a cultivation cost of ₹ 71,515 ha⁻¹. Compared with RDF alone, the combined application treatments increased the cost of cultivation by 6–20%, primarily due to the additional cost of seaweed biostimulants and the labour required for dual application. Treatments involving either foliar spray or soil drenching alone incurred comparatively lower additional expenditure. The findings provide a reliable economic baseline for assessing the cost implications of different seaweed biostimulant application methods and serve as a foundation for evaluating their overall economic viability in soybean cultivation.

Keywords: Soybean, seaweed biostimulant, *kappaphycus alvarezii*, *ascophyllum nodosum*, cost of cultivation, inceptisol

1. Introduction

Soybean (*Glycine max* L. Merrill) is among the most economically important oilseed-cum-pulse crops of the world, valued both as a source of edible oil and as a high-protein feed and food component (Smith and Huyser, 1987)^[1]. India ranks fifth among soybean-producing nations, with Madhya Pradesh, Maharashtra and Rajasthan being the leading producing states (Anonymous, 2024)^[2].

Soybean productivity remains sensitive to a range of environmental constraints across its growth cycle. As a short-day plant, its flowering and maturity are strongly regulated by photoperiod (Garner and Allard, 1930)^[3] and adverse conditions during germination and early establishment can considerably extend crop emergence (Jasinska and Kotecki, 2003)^[4]. Elevated temperatures during flowering and pod development are known to reduce seed number and seed mass (Schlenker and Roberts, 2008; Wheeler *et al.*, 2000; Gibson and Mullen, 1996)^[5, 6, 7], while heat and moisture stress alter the protein and oil composition of the harvested seed (Dornbos and Mullen, 1992; Vollmann *et al.*, 2000)^[8, 9]. Water deficit during critical growth stages further depresses seed yield (Cox and Jolliff, 1986)^[10]. Such yield instability affects the cost-effectiveness of soybean cultivation, making the economic evaluation of any corrective input, including biostimulants, an essential companion to its agronomic evaluation. Biostimulants have emerged as one such corrective input.

They are defined as substances or microorganisms applied to plants, seeds or the root zone with the intention of enhancing nutrient use efficiency and abiotic stress tolerance, independent of their nutrient content (Du Jardin, 2012; Du Jardin, 2015) [11, 12]. Kauffman *et al.* (2007) [13] similarly described biostimulants as agents that promote plant growth through non-nutritional mechanisms. Their principal categories, including seaweed extracts, humic substances, protein hydrolysates and microbial inoculants, have been reviewed extensively (Calvo *et al.*, 2014; Basak, 2008; Yakhin *et al.*, 2017; Halpern *et al.*, 2015; Lu *et al.*, 2024) [14, 15, 16, 17, 18], with a consistent conclusion that biostimulants alleviate abiotic stress and improve nutrient acquisition in crop plants (Van Oosten *et al.*, 2017) [19].

Among the different biostimulant categories, seaweed extracts have been used as fertilizer additives for several decades on account of their content of natural plant growth regulators, amino acids and trace elements (Blunden, 1972; Zodape, 2001) [20, 21]. Seaweeds, comprising nearly 9,000 known macroalgal species, are an abundant and renewable coastal resource (Govindasamy *et al.*, 2011; Chhaya, 1997; Green, 2015) [22, 23, 24] and extracts of genera such as *Kappaphycus* and *Ascophyllum* have been reported to improve seed germination, nutrient content and overall crop quality in a range of field and legume crops (Zodape *et al.*, 2010) [25].

In soybean specifically, seaweed and related biostimulants have been shown to enhance growth, physiological performance and grain quality under both irrigated and rainfed conditions (Rathore *et al.*, 2009; Tandon and Dubey, 2015; Kocira *et al.*, 2018; Szparaga *et al.*, 2018; Kocira *et al.*, 2019) [26, 27, 28, 29, 30, 12]. Reduced-input studies have further shown that biostimulant use can partially compensate for lower doses of nitrogen fertilizer without yield penalty (Kristek *et al.*, 2017) [31] and comparative trials in soybean and blackgram have confirmed measurable growth responses to novel biostimulant formulations (Vishwanantha *et al.*, 2022) [32]. More recent work has extended these findings to organic input combinations (Chaudhary *et al.*, 2023) [33], biological fertilizers under diverse agro-ecologies (Miraezami *et al.*, 2024; Bertham *et al.*, 2026) [34, 35], nutrient-deficiency diagnostics (Latifinia and Eisvand, 2022) [36] and nutrient uptake dynamics under seaweed sap application (Lodhi *et al.*, 2023) [37].

While the agronomic benefits of seaweed biostimulants are well documented, their economic viability is not automatic, since the biostimulant itself represents an additional recurring cost over and above the standard fertilizer schedule. Several workers have specifically examined this economic dimension: Pramanick *et al.* (2013) [38] and Pal *et al.* (2015) [39] reported higher gross and net returns following seaweed sap application in green gram and maize (sweet corn), respectively; Patil *et al.* (2019) [40] and Nayak *et al.* (2020) [41] evaluated the cost-return balance of seaweed extract use in soybean and rice, Garai *et al.* (2019) [42] and Rai *et al.* (2021) [43] examined returns under legume-based cropping sequences; Arioli *et al.* (2021) [44] and Sarita *et al.* (2021) [45] reported profitability responses in grape and wheat; Sebastian (2021) [46] computed the return on investment for seaweed-treated rice; Zarzecka *et al.* (2020) [47] demonstrated that combining a biostimulant with another agronomic input raised the overall cost of cultivation in potato; and Mote *et al.* (2022) [48] showed that the choice of biostimulant source itself altered the cost of cultivation in rice, independent of the yield obtained. Dwivedi *et al.* (2014) [49] additionally reported that increasing seaweed sap concentration altered both productivity and the associated input cost in blackgram. Despite this body of work, the specific cost implication of combining two different

modes of application, namely foliar spray and soil drenching, using two distinct seaweed sources, has not been examined for soybean grown on Inceptisols of the scarcity zone of Maharashtra. The present investigation was, therefore, undertaken to evaluate the effect of different seaweed biostimulant treatments on the cost of cultivation of soybean grown in an Inceptisol.

2. Materials and Methods

2.1 Experimental site

The field experiment was conducted during kharif 2024 at the Post Graduate Institute Research Farm, Department of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahilyanagar, Maharashtra, India (19°34' N latitude, 74° 64' E longitude; elevation 465 m above mean sea level). The site falls in the scarcity zone on the eastern side of the Western Ghats, with an average annual rainfall of about 520 mm, concentrated mainly between June and September. The experimental soil was medium-deep black, belonging to the Inceptisol order, moderately alkaline in reaction (pH 8.43), low in soluble salts (EC 0.19 dS m⁻¹), low in organic carbon (0.45%) and low in calcium carbonate (4.29%). The soil was low in available nitrogen (248 kg ha⁻¹), moderate in available phosphorus (21.02 kg ha⁻¹) and very high in available potassium (328 kg ha⁻¹).

2.2 Experimental design and treatments

The experiment was laid out in a Randomized Block Design with ten treatments replicated thrice, using soybean cv. *Phule Kimaya* (KDS-753) sown at a spacing of 45 cm × 5 cm on 12th July 2024. The gross and net plot sizes were 4.00m × 3.60 m and 3.80m × 2.70m, respectively. The ten treatments comprised: T1, absolute control; T2, general recommended dose of fertilizer, GRDF (50:75:45 kg N:P₂O₅:K₂O ha⁻¹ + 10 t FYM ha⁻¹); T3 and T4, GRDF with foliar spray of 0.50% and 0.75% seaweed extract of *Kappaphycus alvarezii* at 30 and 45 days after sowing (DAS), respectively; T5, GRDF with soil drenching of 1% *Kappaphycus alvarezii* extract at 20 and 35 DAS; T6, GRDF with the combined foliar spray (0.50%) and drenching (1%) of *Kappaphycus alvarezii*; T7 and T8, GRDF with foliar spray of 0.50% and 0.75% *Ascophyllum nodosum* extract, respectively; T9, GRDF with drenching of 1% *Ascophyllum nodosum* extract; and T10, GRDF with the combined foliar spray (0.50%) and drenching (1%) of *Ascophyllum nodosum* extract.

2.3 Estimation of cost of cultivation

The cost of cultivation (ha⁻¹) for each treatment was worked out by accounting for all the operational expenses incurred during crop production, viz., land preparation, seed and sowing, FYM and fertilizer material and their application, cost of the seaweed biostimulant procured and its application through foliar spray and/or soil drenching, plant protection, irrigation, intercultural operations and harvesting, based on the prevailing market rates of inputs, machinery and human labour during the cropping season. Since the biostimulant sources, their concentration and the number and mode of application varied across treatments, the incremental cost over the control and over the GRDF-alone treatment was separately worked out for each treatment to isolate the specific contribution of the biostimulant component to the total cultivation cost.

2.4 Statistical analysis

The data on cost of cultivation were subjected to analysis of variance as applicable to a Randomized Block Design (Panse and Sukhatme, 1995) [50]. Wherever the treatment effects were found significant, the critical difference (CD) was calculated at 5 per cent level of probability for comparison of treatment means.

3. Results and Discussion

3.1 Cost of cultivation

The data on the cost of cultivation of soybean as influenced by different seaweed biostimulant treatments are presented in Table 1 and illustrated in Fig. 1.

Variables	C= Total cost of cultivation (₹ ha ⁻¹) Y= Soybean grain yield (q ha ⁻¹) P= Market price of soybean (₹ q ⁻¹) R= Target benefit-cost (B:C) ratio	
1. Gross Returns (GR)	GR=Y×P	where, GR= Gross returns (₹ ha ⁻¹)
2. Net Returns (NR)	NR=(Y×P)-C or NR=GR-C	where, NR= Net returns (₹ ha ⁻¹)
3. Benefit-Cost Ratio (B:C Ratio)	R=(Y×P)/(C)	where, R= Benefit-cost ratio
4. Break-even Yield (at R = 1.0 or NR = 0)	Y _{BE} =(C)/(P)	where, Y _{BE} = Break-even grain yield (qha ⁻¹)
5. Required Grain Yield for Target B:C Ratio (R)	Y _{req} =(R×C)/(P)	where, Y _{req} = Required grain yield (qha ⁻¹)
6. Required Market Price for Target B:C Ratio (R)	P _{req} =(R×C)/(Y)	where, P _{req} = Required market price (₹ q ⁻¹)
7. Marginal Benefit-Cost Ratio (MBCR)(Considering T ₂ as the baseline treatment)	MBCR=((Y _{Treatment} -Y _{T2})×P)/(C _{Treatment} -C _{T2})	where, Y _{Treatment} = Grain yield of the respective treatment (qha ⁻¹) Y _{T2} = Grain yield under GRDF (T ₂) (qha ⁻¹) C _{Treatment} = Cost of cultivation of the respective treatment (₹ ha ⁻¹) C _{T2} = Cost of cultivation under GRDF (T ₂) (₹ ha ⁻¹)

Compared with the absolute control, the application of GRDF alone (T₂) increased the cost of cultivation by approximately 32%, reflecting the expenditure on fertilizers and FYM. The addition of seaweed biostimulants over GRDF further increased cultivation costs by about 5–8% under foliar spray treatments (T₃, T₄ and T₇), 7–11% under soil drenching treatments (T₅, T₈ and T₉ and 16–20% under combined foliar spray and soil drenching treatments (T₆ and T₁₀) (Fig. 1). The higher cultivation cost under combined treatments was mainly attributed to the greater quantity of seaweed biostimulant required and the additional labour involved in the second mode of application, while the basal fertilizer schedule remained identical across all fertilized treatments.

The comparatively higher cultivation cost recorded under the *Ascophyllum nodosum*-based treatments (T₇-T₁₀) than the corresponding *Kappaphycus alvarezii*-based treatments (T₃-T₆) reflects the higher procurement cost of the former seaweed source (Table 1). Similar sourcedependent differences in cultivation cost have been reported in maize, fenugreek and other cropping systems (Basavaraja *et al.*, 2018; Mafakheri and Asghari, 2018; Ghosh *et al.*, 2020) [51, 52, 53]. Kumari *et al.* (2023) [54], López-Serrano *et al.* (2026) [55] and Shahrajabian *et al.* (2023) [56] likewise emphasized that the source of the biostimulant and the application rate are important determinants of production cost.

The present findings corroborate earlier reports that increasing the dose or intensity of biostimulant application raises cultivation costs because of higher input and labour requirements (Patil *et al.*, 2019; Zarzecka *et al.*, 2020; Mote *et al.*, 2022; Sarita *et al.*, 2021; Rai *et al.*, 2021; Garai *et al.*, 2019; Pal *et al.*, 2015; Arioli *et al.*, 2021; Dwivedi *et al.*, 2014) [40, 47, 48, 45, 43, 42, 39, 44, 49]. Therefore, both the application method and the seaweed source are important determinants of cultivation cost and should be considered while formulating economically viable recommendations for soybean production.

The cost of cultivation ranged from F46, 887ha⁻¹ under the absolute control (T₁) to F74, 158ha⁻¹ under the combined foliar spray and drenching of *Ascophyllum nodosum* (T₁₀). Among the treatments, T₁₀ recorded the highest cultivation cost, followed by T₆ (F71, 515ha⁻¹) T₉ (F70, 169 ha⁻¹), T₅ (968, 390ha⁻¹) and T₈ (968, 078ha⁻¹), whereas the lowest cost among the fertilized treatments was recorded under T₂ (F61, 804ha⁻¹) (Table 1, Fig. 1).

3.2 Economic analysis

The economic analysis of soybean under different seaweed biostimulant treatments, including break-even yield, required grain yield, benefit–cost ratio (B:C ratio) and net return, is presented in Table 2, while the grain and stover yield obtained under different treatments is illustrated in Fig. 2.

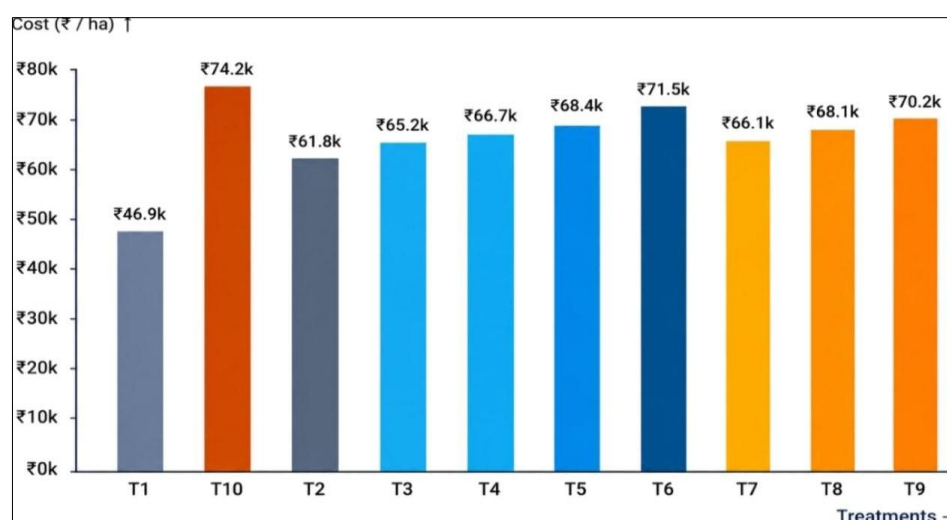
The break-even yield increased from 9.58 q ha⁻¹ under the absolute control (T₁) to 15.16 q ha⁻¹ under the combined application of *Ascophyllum nodosum* (T₁₀), while the required grain yield increased from 14.38 to 22.74 q ha⁻¹ across treatments, reflecting the progressive increase in cultivation cost (Table 2). Similarly, the benefit–cost ratio declined from 2.30 under T₁ to 1.45 under T₁₀, whereas net return decreased from 60,737 ha⁻¹ to ₹ F33, 466ha⁻¹ with increasing investment in seaweed biostimulant application (Table 2). These findings indicate that higher cultivation costs require proportionately greater productivity to maintain economic profitability.

Although the cultivation cost increased with the combined application of seaweed biostimulants, grain and stover yields also improved compared with the control and GRDF alone, particularly under the combined application treatments (Fig. 2). This suggests that the additional expenditure incurred on seaweed biostimulants may be compensated by enhanced crop productivity, provided that the yield advantage is sufficient to offset the increased production cost.

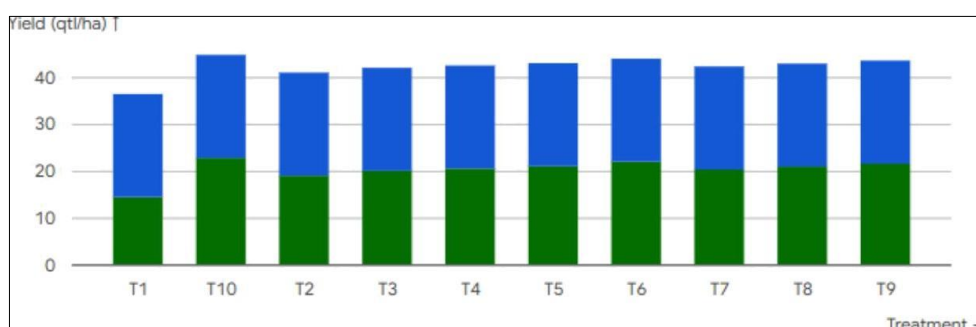
These observations agree with earlier studies reporting that seaweed biostimulants enhance crop growth, yield and economic returns in several field crops, including soybean, rice and chickpea (Rathore *et al.*, 2009; Pramanick *et al.*, 2013; Nayak *et al.*, 2020; Kumari *et al.*, 2023) [26, 38, 41, 54]. Therefore, economic recommendations should be based on a combined evaluation of cultivation cost, crop productivity and profitability rather than on input cost alone.

Table 1: Cost of cultivation (ha⁻¹) of soybean as influenced by different Bio-stimulant[₹] - treatment

Trt. No.	Treatment details	Cost of cultivation (₹ ha ⁻¹)
T1	Absolute control	46,887
T2	GRDF (50:75:45 N:P2O5:K2O kg ha ⁻¹ + 10 t ha ⁻¹ FYM)	61,804
T3	GRDF + foliar spray of 0.50% seaweed extract of Kappaphycus alvarezii at 30 and 45 DAS	65,183
T4	GRDF + foliar spray of 0.75% seaweed extract of Kappaphycus alvarezii at 30 and 45 DAS	66,745
T5	GRDF + drenching of 1% seaweed extract of Kappaphycus alvarezii at 20 and 35 DAS	68,390
T6	GRDF + foliar spray of 0.50% seaweed extract of Kappaphycus alvarezii at 30 and 45 DAS + drenching of 1% seaweed extract of Kappaphycus alvarezii at 20 and 35 DAS	71,515
T7	GRDF + foliar spray of 0.50% seaweed extract of Ascophyllum nodosum at 30 and 45 DAS	66,081
T8	GRDF + foliar spray of 0.75% seaweed extract of Ascophyllum nodosum at 30 and 45 DAS	68,078
T9	GRDF + drenching of 1% seaweed extract of Ascophyllum nodosum at 20 and 35 DAS	70,169
T10	GRDF + foliar spray of 0.50% seaweed extract of Ascophyllum nodosum at 30 and 45 DAS + drenching of 1% seaweed extract of Ascophyllum nodosum at 20 and 35 DAS	74,158
	SE (m±)	2,177
	CD at 5%	6,593

**Fig 1:** Cost of cultivation (ha⁻¹) of soybean as influenced by different biostimulant[₹] - treatment**Table 2:** Economic analysis of soybean under different seaweed bio-stimulant treatments. Figure 2. Yield performance of soybean under different seaweed Bio-stimulant treatments.

ID	Cost (₹)	B.E. Yield	Req. Yield	B:C Ratio	Net Return (₹)
T1	46,887	9.58	14.38	2.30	60,737
T2	61,804	12.63	18.95	1.74	45,820
T3	65,183	13.32	19.99	1.65	42,441
T4	66,745	13.64	20.47	1.61	40,879
T5	68,390	13.98	20.97	1.57	39,234
T6	71,515	14.62	21.93	1.50	36,109
T7	66,081	13.51	20.26	1.63	41,543
T8	68,078	13.92	20.87	1.58	39,546
T9	70,169	14.34	21.52	1.53	37,455
T10	74,158	15.16	22.74	1.45	33,466

**Fig 2:** Yield varied across treatments, with T10 recording the highest overall yield.

4. Conclusion

The cost of cultivation of soybean increased progressively with the addition of seaweed biostimulants over the general recommended dose of fertilizer and was highest under the treatments combining both foliar spray and soil drenching. The combined application of *Ascophyllum nodosum* (T10) and of *Kappaphycus alvarezii* (T6) recorded the highest cultivation costs among all treatments, exceeding the cost of GRDF alone by about 20 and 16 per cent, respectively, largely on account of the additional biostimulant material and labour required for the second mode of application. Since the combined treatments also represent the more input-intensive options, their adoption needs to be weighed against the yield and quality advantage they confer and the present cost data provide the necessary baseline for such an economic evaluation in soybean grown on Inceptisols.

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