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Effect of biostimulant seaweed on soil physico-chemical properties and on available N, P, K in the rhizosphere soil of cowpea (*Vigna Unguiculata* L.) WALP)

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Abstract

A field experiment was conducted during the *rabi*, 2025-26 to evaluate the effect of soil-applied biostimulant seaweed, alone and in combination with graded levels of the recommended dose of fertilizer (RDF), on soil physico-chemical properties and nutrient availability in the rhizosphere of cowpea (*Vigna unguiculata* (L.) Walp.) cv. Vijaya. The experiment was laid out in a factorial randomized block design comprising five fertilizer levels (100% RDF, 75% RDF, 50% RDF, seaweed alone and an absolute control) and three seaweed levels (0, 25 and 50 kg ha⁻¹), replicated four times. Rhizosphere soil was sampled at the vegetative and flowering stages and after harvest and analysed for pH, electrical conductivity (EC), organic carbon and available nitrogen (N), phosphorus (P), potassium (K). Soil application of seaweed at increasing levels progressively and significantly ($P < 0.05$) enhanced available N, P, K status at every growth stage, while soil pH and EC showed only marginal, largely favourable shifts. Combining 100% RDF with 50 kg seaweed ha⁻¹ (T1S50) consistently produced the highest nutrient availability at all three stages, for example raising available nitrogen from 80.6 kg ha⁻¹ in the absolute control to 633.5 kg ha⁻¹ at the vegetative stage, whereas seaweed applied alone at 50 kg ha⁻¹ (T4S50) maintained nutrient levels intermediate between the unfertilized control and the lower RDF levels, without meeting the nutrient supply of 50% RDF. Soil organic carbon likewise improved most under the combined fertilizer-seaweed treatments. These findings indicate that seaweed biostimulant, used as a supplement to inorganic fertilizer, can substantially improve rhizosphere fertility in cowpea, offering scope for reducing the reliance on inorganic fertilizer while sustaining soil nutrient status.

Keywords: Cowpea; seaweed biostimulant; rhizosphere; soil fertility; available nutrients

Introduction

Pulses are a vital and low-cost source of dietary protein and help sustain soil fertility through biological nitrogen fixation, yet India's per-capita pulse availability remains below the WHO-recommended 80 g day⁻¹. Among pulses, cowpea (*Vigna unguiculata* (L.) Walp.) is widely grown in the arid and semi-arid tracts of India for its short duration, drought tolerance and dual role as a grain and fodder crop, with fodder-type cowpea reported to yield up to 17.22 t ha⁻¹ green fodder and 18.62% crude protein under favourable management (Singh, 2023^[19]). Continuous, imbalanced use of chemical fertilizers, however, has depleted soil organic matter and degraded soil health on many smallholder farms. Since crop performance is largely governed by rhizosphere conditions pH, EC, organic carbon and available nutrient pools inputs that favourably alter rhizosphere chemistry are central to improving nutrient-use efficiency in cowpea.

Seaweed-derived biostimulants offer a promising, eco-friendly alternative. Classified into *Rhodophyceae*, *Chlorophyceae* and *Phaeophyceae*, seaweeds are rich in bioactive polysaccharides, phenolics, vitamins and phytohormones (Penalver *et al.*, 2020^[16]; Wang *et al.*, 2018)^[24], and act as biostimulants rather than fertilizers, enhancing nutrient-use efficiency and stress tolerance without supplying nutrients at fertilizer-equivalent levels (Yakhin *et al.*, 2017^[25]; Du Jardin, 2015)^[7]. Their application improves soil microbial activity, cation exchange capacity and availability of N, P, K (Circuncisão *et al.*, 2018^[4]; Vicente *et al.*, 2023)^[22], while also promoting beneficial rhizosphere organisms such as *Rhizobium* and mycorrhizae (Alam *et al.*, 2013)^[1]. Soil application of seaweed granules has been shown to improve root growth,

nutrient-use efficiency and soil biological properties (Margal *et al.*, 2023^[12]; Supriya *et al.*, 2023) ^[21], and a recent meta-analysis confirmed consistent yield gains from soil-directed seaweed application in legumes (Pérez-Oñate *et al.*, 2026) ^[17]. However, little is known about how graded seaweed doses interact with graded fertilizer levels to influence rhizosphere nutrient dynamics in cowpea across growth stages.

The present study was therefore undertaken to evaluate the individual and combined effects of graded seaweed levels (0, 25 and 50 kg ha⁻¹) and fertilizer levels (100%, 75% and 50% RDF, seaweed alone and absolute control) on soil reaction, EC, organic carbon and the availability of N, P and K in the rhizosphere of cowpea at the vegetative, flowering and post-harvest stages.

Material And Methods

The field experiment was conducted during *rabi*, 2025-26 at the Forage Unit, Agricultural Research Institute (ARI), on sandy clay loam soil. Initial soil samples were collected before treatment imposition and analysed for physico-chemical properties as baseline values for comparison with treatment means. Cowpea cv. Vijaya was sown at 15-20 kg ha⁻¹ seed rate in plots of 4.8 × 4 m size, with RDF of 20:50:0 kg N:P₂O₅:K₂O ha⁻¹. Five fertilizer levels (T1: 100% RDF, T2: 75% RDF, T3: 50% RDF, T4: seaweed alone, T5: absolute control) were combined factorially with three levels of soil-applied biostimulant seaweed (0, 25 and 50 kg ha⁻¹; source: SBACRF, Karaikudi), giving fifteen treatment combinations laid out in a factorial randomized block design (5 fertilizer levels × 3 seaweed levels), replicated four times. The seaweed biostimulant was analysed prior to application for available N, P, K and protein content and applied to the soil at 0 (S0), 25 (S25) and 50 (S50) kg ha⁻¹ as per the treatment schedule. Seaweed was applied as a single soil application before sowing. Rhizosphere soil samples were collected at the vegetative, flowering and post-harvest stages and analysed for soil texture,

pH, EC, organic carbon and available N, P, K. Soil pH and EC were determined in soil-water suspension, while organic carbon and available macronutrients were estimated by standard laboratory procedures (Subbiah and Asija, 1956 ^[20], for available N, Olsen *et al.*, 1954 ^[14], for available phosphorus in soils).

Statistical analysis

Data recorded at each growth stage were subjected to analysis of variance appropriate to the factorial randomized block design, following the procedure of Panse and Sukhatme (1985) ^[13]. Treatment means were compared using the critical difference (CD) at P = 0.05 and standard error (SE) and coefficient of variation (CV %) were computed for the seaweed (S) main effect, the fertilizer treatment (T) main effect, and the S × T interaction at each stage.

Results

Soil application of biostimulant seaweed, both alone and in combination with graded levels of RDF, significantly (*P* < 0.05) influenced soil reaction, electrical conductivity, organic carbon and the availability of N, P and K in the rhizosphere of cowpea at the vegetative, flowering and post-harvest stages. The main effects of seaweed level (S) and fertilizer treatment (T), together with their interaction (S × T), were significant for every parameter studied. Results for each parameter across the three growth stages are summarised below and in Tables 1-6.

Soil reaction (pH) and electrical conductivity

The initial soil of the experimental site was moderately alkaline (pH 8.23) with an EC of 0.59 dS m⁻¹. Application of fertilizer and seaweed, singly or in combination, brought about a small but consistent reduction in soil pH relative to the absolute control at every stage; the fully fertilized, high-seaweed combination (T1S50) recorded the lowest pH (8.10, 8.08 and 8.11 at the vegetative, flowering and post-harvest stages, respectively), whereas the absolute control (T5S0) remained closest to the initial value (Table 1). Within each fertilizer level, increasing the seaweed dose from 0 to 50 kg ha⁻¹ produced a small further decline in pH, consistent with the acidifying effect commonly associated with the organic acids and decomposing organic matter contributed by seaweed and fertilizer inputs.

Table 1: Effect of seaweed levels and fertilizer treatments on soil pH in the rhizosphere soil of cowpea at the vegetative, flowering and post-harvest stages

Fertilizer levels	Soil pH at crop growth stages											
	Vegetative stage				Flowering stage				Post-harvest stage			
	seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)			
	S0	S25	S50	Mean	S0	S25	S50	Mean	S0	S25	S50	Mean
T1: 100% RDF	8.02	8.06	8.1	8.06	8.03	8.07	8.11	8.07	8.03	8.07	8.11	8.07
T2: 75% RDF	8.08	8.11	8.15	8.11	8.08	8.12	8.16	8.12	8.08	8.12	8.16	8.12
T3: 50% RDF	8.12	8.16	8.2	8.16	8.13	8.17	8.21	8.17	8.13	8.17	8.21	8.17
T4: Only seaweed	8.18	8.22	8.25	8.22	8.18	8.22	8.26	8.22	8.18	8.22	8.26	8.22
T5: Control	8.22	8.25	8.28	8.25	8.22	8.26	8.3	8.26	8.22	8.26	8.3	8.26
Mean	8.12	8.16	8.2	8.16	8.13	8.17	8.21	8.17	8.13	8.17	8.21	8.17
CV (%)	0.333				0.271				0.271			
				S*T				S*T				S*T
CD (P=0.05)	0.017	0.022		0.038	0.014	0.018		0.031	0.014	0.018		0.031
SE (+/-)	0.006	0.007		0.013	0.005	0.006		0.011	0.005	0.006		0.011
Initial	8.23											

Electrical conductivity (ds m⁻¹)

Electrical conductivity showed the opposite trend: EC increased significantly with both increasing fertilizer level and increasing seaweed dose, from 0.60-0.65 dS m⁻¹ under the absolute control to 0.81-1.00 dS m⁻¹ under T1S50, the values remaining well

within the non-saline range at all stages (Table 2). EC was highest at the vegetative stage and declined progressively through flowering and post-harvest, reflecting nutrient uptake by the growing crop and leaching over the cropping period.

Table 2: Effect of seaweed levels and fertilizer treatments on electrical conductivity (dS m⁻¹) in the rhizosphere soil of cowpea at vegetative, flowering and post-harvest stages

Fertilizer levels	Soil EC (dS m ⁻¹) at crop growth stages											
	Vegetative stage				Flowering stage				Post-harvest stage			
	seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)			
	S0	S25	S50	Mean	S0	S25	S50	Mean	S0	S25	S50	Mean
T1: 100% RDF	0.81	0.92	1.00	0.91	0.71	0.84	0.90	0.81	0.65	0.76	0.81	0.74
T2: 75% RDF	0.76	0.87	0.93	0.85	0.68	0.80	0.87	0.78	0.62	0.71	0.76	0.70
T3: 50% RDF	0.70	0.79	0.85	0.78	0.65	0.71	0.75	0.70	0.57	0.64	0.69	0.63
T4: Only seaweed	0.65	0.74	0.79	0.72	0.59	0.66	0.71	0.65	0.53	0.60	0.64	0.59
T5: Control	0.60	0.61	0.63	0.61	0.54	0.56	0.57	0.55	0.49	0.50	0.51	0.50
Mean	0.70	0.78	0.84	0.77	0.63	0.71	0.76	0.70	0.57	0.64	0.68	0.63
CV (%)	7.957				8.126				5.317			
	S		T	S*T	S		T	S*T	S		T	S*T
CD (P=0.05)	0.039		0.051	0.088	0.036		0.047	0.081	0.021		0.028	0.048
SE (+/-)	0.014		0.018	0.031	0.013		0.016	0.028	0.007		0.010	0.017
Initial	0.59											

Soil organic carbon

Table 3: Effect of seaweed levels and fertilizer treatments on soil organic carbon (%) in the rhizosphere soil of cowpea at the vegetative, flowering and post-harvest stages

Fertilizer levels	soil organic carbon (%) at crop growth stages											
	Vegetative stage				Flowering stage				Post harvest stage			
	seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)			
	S0	S25	S50	Mean	S0	S25	S50	Mean	S0	S25	S50	Mean
T1: 100% RDF	0.81	0.92	1.00	0.91	0.71	0.84	0.90	0.81	0.65	0.76	0.81	0.74
T2: 75% RDF	0.76	0.87	0.93	0.85	0.68	0.80	0.87	0.78	0.62	0.71	0.76	0.70
T3: 50% RDF	0.70	0.79	0.85	0.78	0.65	0.71	0.75	0.70	0.57	0.64	0.69	0.63
T4: Only seaweed	0.65	0.74	0.79	0.72	0.59	0.66	0.71	0.65	0.53	0.60	0.64	0.59
T5: Control	0.60	0.61	0.63	0.61	0.54	0.56	0.57	0.55	0.49	0.50	0.51	0.50
Mean	0.70	0.78	0.84	0.77	0.63	0.71	0.76	0.70	0.57	0.64	0.68	0.63
CV (%)	7.957				8.126				5.317			
	S	T	S*T		S	T	S*T		S	T	S*T	
CD (P=0.05)	0.039	0.051	0.088		0.036	0.047	0.081		0.021	0.028	0.048	
SE (+/-)	0.014	0.018	0.031		0.013	0.016	0.028		0.007	0.010	0.017	
Initial	0.59											

Soil organic carbon (SOC) increased significantly with both seaweed level and fertilizer treatment at all three stages, from an initial value of 0.35% before treatment imposition (Table 3). The combination of 100% RDF with 50 kg seaweed ha⁻¹ (T1S50) recorded the highest SOC at every stage (0.58% at vegetative, 0.68% at flowering and 0.65% at post-harvest), while the absolute control (T5) recorded the lowest values throughout (0.34-0.39%). SOC rose from vegetative to flowering and then declined marginally by the post-harvest stage, mirroring the seasonal pattern of organic matter addition through root turnover and decomposition of applied seaweed followed by mineralization after crop maturity. The seaweed main effect alone raised mean SOC from 0.41-0.46% at S0 to 0.50-0.54% at S50 across stages, underscoring the direct contribution of seaweed-derived organic matter to the soil carbon pool independent of the fertilizer level applied.

Available nitrogen

Available nitrogen responded strongly to both seaweed and fertilizer application at all three growth stages (Table 4).

Increasing the seaweed level from 0 to 50 kg ha⁻¹ raised mean available N from 222.15 to 412.82 kg ha⁻¹ at the vegetative stage, 161.63 to 325.45 kg ha⁻¹ at flowering, and 179.38 to 361.46 kg ha⁻¹ post-harvest. The percent increases of 86, 101 and 102, respectively, over the control. Among fertilizer treatments, available N declined progressively from 100% RDF (T1) through 75% RDF (T2), 50% RDF (T3) and seaweed alone (T4) down to the absolute control (T5) at every stage; seaweed applied alone at 50 kg ha⁻¹ (207.5-319.9 kg ha⁻¹ across stages) did not match the available N supplied by 50% RDF, but remained significantly higher than the control. The S × T interaction was significant at all stages, with the combined treatment of 100% RDF and 50 kg seaweed ha⁻¹ (T1S50) recording the highest available N throughout (633.47, 501.76 and 558.21 kg ha⁻¹ at the vegetative, flowering and post-harvest stages, respectively) representing the increases of 686%, 631% and 799% over the corresponding absolute control values, confirming that seaweed and fertilizer act complementarily rather than substitutively in sustaining rhizosphere nitrogen availability.

Table 4: Effect of seaweed levels and fertilizer treatments on available nitrogen (kg ha^{-1}) in the rhizosphere soil of cowpea at the vegetative, flowering and post-harvest stages

Fertilizer levels	Available nitrogen (kg ha ⁻¹) of crop growth stages											
	Vegetative stage				Flowering stage				Post-harvest stage			
	seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)			
	S0	S25	S50	Mean	S0	S25	S50	Mean	S0	S25	S50	Mean
T1: 100% RDF	395.1	514.3	633.5	514.3	288.5	388.9	501.8	393.1	326.1	439.0	558.2	441.1
T2: 75% RDF	313.6	439.0	551.9	434.9	225.8	326.1	432.8	328.2	257.2	370.1	482.9	370.1
T3: 50% RDF	238.3	357.5	470.4	355.4	169.3	263.4	370.1	267.6	188.2	301.1	407.7	298.9
T4: Only seaweed	83.10	219.5	319.9	207.5	55.82	163.1	250.9	156.6	63.35	181.9	275.9	173.7
T5: Control	80.60	80.6	88.44	83.21	68.68	64.92	71.81	68.47	62.09	67.74	82.48	70.77
Mean	222.2	322.2	412.8	319.1	161.6	241.3	325.5	242.8	179.4	271.9	361.5	270.9
CV (%)	12.01				15.27				12.88			
	S	T	S*T		S	T	S*T		S	T	S*T	
CD (P=0.05)	24.46	31.58	54.70		23.65	30.53	52.89		22.27	28.75	49.80	
SE (+/-)	8.57	11.06	19.16		8.29	10.70	18.53		7.80	10.07	17.45	
Initial	87.81											

Available phosphorus

Available phosphorus increased significantly with rising seaweed level at every stage, from 37.37 to 62.89 kg ha^{-1} (vegetative), 50.39 to 79.68 kg ha^{-1} (flowering) and 43.75 to 68.62 kg ha^{-1} (post-harvest) as the seaweed dose rose from 0 to 50 kg ha^{-1} , representing increases of 68%, 58% and 57% over the absolute control (Table 5). Fertilizer treatments followed the expected gradient, with 100% RDF (T1) recording the highest mean available P at all stages (68.22, 87.11 and 75.17 kg ha^{-1}) and the absolute control (T5) the lowest (27.43, 35.68 and 30.68 kg ha^{-1});

seaweed applied alone did not equal the phosphorus supplied by 50% RDF but was significantly superior to the control. The interaction between seaweed and fertilizer was consistently significant and the combined treatment T1S50 recorded the highest available phosphorus at each stage (85.15, 105.33 and 92.31 kg ha^{-1}), representing increases of 221%, 225% and 227% over the respective lowest-value treatment combinations, indicating that seaweed application enhances phosphorus availability most strongly when applied together with adequate fertilizer.

Table 5: Effect of seaweed levels and fertilizer treatments on available phosphorus (kg ha^{-1}) in the rhizosphere soil of cowpea at the vegetative, flowering and post-harvest stages

Fertilizer levels	Available phosphorus (kg ha ⁻¹) of crop growth stages											
	Vegetative stage				Flowering stage				Post harvest stage			
	seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)			
	S0	S25	S50	Mean	S0	S25	S50	Mean	S0	S25	S50	Mean
T1: 100% RDF	49.3	70.2	85.2	68.2	67.6	88.4	105.3	87.1	56.5	76.7	92.3	75.12
T2: 75% RDF	44.1	62.4	76.7	61.1	61.1	80.6	96.9	79.5	51.3	69.5	84.5	68.4
T3: 50% RDF	36.9	53.3	67.6	52.6	53.3	70.2	85.8	69.8	45.4	61.1	72.8	59.8
T4: Only seaweed	29.8	44.1	56.5	43.5	37.7	58.5	72.8	56.3	31.8	50.0	63.7	48.5
T5: Control	26.6	27.2	28.5	27.4	32.4	36.9	37.6	35.7	33.7	28.5	29.8	30.7
Mean	37.4	51.4	62.9	50.6	50.4	66.9	79.7	65.7	43.8	57.2	68.6	56.5
CV (%)	7.888				8.539				8.158			
	S	T	S*T		S	T	S*T		S	T	S*T	
CD (P=0.05)	2.55	3.29	5.69		3.58	4.62	8.00		2.94	3.80	6.58	
SE (+/-)	0.89	1.15	1.99		1.25	1.62	2.80		1.03	1.33	2.31	
Initial	26.89											

Available potassium

Available potassium increased progressively with seaweed level, though the relative gains were more modest than for N and P, rising from 420.2 to 496.5 kg ha^{-1} (vegetative), 467.7 to 555.5 kg ha^{-1} (flowering) and 366.6 to 441.4 kg ha^{-1} (post-harvest) as seaweed level rose from 0 to 50 kg ha^{-1} increases of 18%, 19% and 20%, respectively (Table 6). Notably, potassium showed a clear response even in the seaweed-alone treatment (T4) relative to the absolute control at every seaweed level, consistent with the naturally high potassium content of seaweed biomass. Among

fertilizer treatments, 100% RDF (T1) recorded the highest available K at all stages despite the RDF itself containing no supplemental K, reflecting the residual soil K status and its interaction with N and P nutrition. The S $\times$ T interaction was significant throughout, with T1S50 recording the highest available K at every stage (558.3, 622.7 and 508.1 kg ha^{-1}) and the absolute control (T5S0) the lowest (374.0, 413.2 and 317.6 kg ha^{-1}), representing increases of 49%, 51% and 60% over the respective controls.

Table 6: Effect of seaweed levels and fertilizer treatments on available potassium (kg ha^{-1}) in the rhizosphere soil of cowpea at the vegetative, flowering and post-harvest stages

Fertilizer levels	Available potassium (kg ha ⁻¹) of crop growth stages											
	Vegetative stage				Flowering stage				Post harvest stage			
	seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)				seaweed levels (kg ha ⁻¹)			
	S0	S25	S50	Mean	S0	S25	S50	Mean	S0	S25	S50	Mean
T1: 100% RDF	465.1	509.1	558.3	510.8	522.8	569.6	622.7	571.7	411.9	455.8	508.1	458.6
T2: 75% RDF	442.1	482.9	528.3	484.4	494.0	537.6	591.1	540.9	391.1	427.3	476.0	431.5
T3: 50% RDF	419.9	456.1	497.1	457.7	469.2	507.9	558.0	511.7	369.3	399.7	441.7	403.6
T4: Only seaweed	399.8	427.0	465.2	430.7	439.5	477.4	522.8	479.9	343.4	373.4	409.1	375.3
T5: Control	374.0	398.0	433.5	401.8	413.2	447.2	483.0	447.8	317.6	341.9	372.2	343.9
Mean	420.2	454.6	496.5	457.1	467.7	507.9	555.5	510.4	366.6	399.6	441.4	402.6
CV (%)	8.109				8.087				8.115			
	S		T	S*T	S		T	S*T	S		T	S*T
CD (P=0.05)	23.65		30.54	52.89	26.34		34.01	58.90	20.85		26.92	46.62
SE (+/-)	8.29		10.70	18.53	9.23		11.92	20.64	7.30		9.43	16.33
Initial	384.92											

Discussion

Soil reaction, electrical conductivity and organic carbon

The marginal decline in soil pH observed under combined seaweed and fertilizer treatments is consistent with the release of organic acids during decomposition of seaweed biomass and the nitrification of applied ammoniacal fertilizer, both of which contribute hydrogen ions to the soil solution. Because the initial soil was moderately alkaline, this small acidifying effect is agronomically favourable, as it would tend to improve the availability of several plant nutrients, particularly phosphorus and micronutrients, whose solubility increases as pH moves closer to neutral. James *et al.* (2025) ^[10], reported that seaweed-based biostimulants positively influenced soil physicochemical properties, supporting the present findings. The concurrent rise in EC with increasing seaweed and fertilizer levels reflects the addition of soluble mineral salts and organic solutes from both inputs; the fact that EC remained well below levels associated with salinity stress at all stages indicates that seaweed application at the doses used here (up to 50 kg ha^{-1}) can be considered safe from a soil-salinity standpoint. The consistent increase in soil organic carbon under seaweed treatment corroborates the widely reported role of seaweed biomass as a direct source of labile organic matter and as a stimulant of microbial decomposition processes in soil. De Sosa *et al.* (2023) ^[6], also demonstrated that seaweed-based organic amendments improved soil organic matter

Available nitrogen, phosphorus, potassium

The significantly higher available nitrogen recorded under seaweed treatment relative to the control, even in absence of any inorganic fertilizer (T4), supports the observations of Rathore *et al.* (2009) ^[18], who reported enhanced nutrient uptake in legume crops following seaweed extract application and is consistent with the improved rhizosphere nitrogen availability reported by Deepana *et al.* (2021) ^[5], in rice following soil application of seaweed extract. The progressive rise in available phosphorus with seaweed level agrees with the findings of Chen *et al.* (2022) ^[3], who observed that seaweed extract supplementation significantly enhanced available phosphorus and potassium in rhizosphere soil, an effect attributed to the organic acids and phosphatase stimulating compounds present in seaweed biomass that can solubilize otherwise fixed soil phosphorus. The relatively strong potassium response even under the seaweed-alone treatment is consistent with the well-documented, naturally high potassium content of marine macroalgae. Karthikeyan and Shanmugam (2017) ^[11], similarly reported that a potassium-rich biostimulant derived from *Kappaphycus alvarezii* improved soil

and plant potassium status in sugarcane, attributing the effect to the readily soluble form in which potassium occurs within seaweed tissue. The present results, in which available potassium increased significantly with seaweed level regardless of the fertilizer treatment applied, support the conclusion that seaweed biostimulants can serve as a valuable supplementary source of plant-available potassium, of particular relevance for legume crops such as cowpea that have a substantial potassium requirement during pod development.

Combined effect of seaweed and fertilizer application

Across every parameter examined, the combination of the full recommended dose of fertilizer with the higher seaweed level 100% RDF + $50 \text{ kg seaweed ha}^{-1}$ (T1S50) consistently produced the greatest improvement in rhizosphere fertility, exceeding the effect of either input applied alone. This complementary, rather than substitutive, relationship between seaweed and mineral fertilizer is consistent with reports that integrated application of seaweed-based biostimulants with recommended fertilizer levels enhances nutrient availability (Banjare *et al.*, 2022 ^[2]; Hussain *et al.*, 2021^[8]; Nivetha *et al.*, 2024) ^[13]. The mechanism most plausibly involves seaweed-derived organic compounds stimulating microbial decomposition and nutrient mineralization, while the mineral fertilizer supplies the immediate nutrient pool that seaweed's bioactive constituents can help retain and cycle more efficiently within the rhizosphere. The consistently intermediate performance of the seaweed-alone treatment relative to the fertilizer gradient further indicates that, while seaweed cannot fully replace inorganic fertilizer under the conditions of this trial, it can meaningfully reduce the fertilizer requirement when the two are used together, offering a pathway toward more resource-efficient nutrient management in cowpea.

Conclusion

Soil application of biostimulant seaweed significantly improved rhizosphere fertility in cowpea at the vegetative, flowering and post-harvest stages, enhancing organic carbon and the availability of nitrogen, phosphorus and potassium. While producing a small, agronomically favourable reduction in soil pH without any indication of salinity risk. The combination of the full recommended dose of fertilizer with $50 \text{ kg seaweed ha}^{-1}$ consistently gave the greatest improvement in rhizosphere nutrient status across all parameters, confirming that seaweed and mineral fertilizer act complementarily rather than as substitutes for one another. Seaweed applied alone significantly improved soil fertility relative to the absolute control but did not match the

nutrient supply achieved with 50% of the recommended fertilizer dose, indicating that under the conditions of this study seaweed is best deployed as a fertility-enhancing supplement integrated with a reduced, rather than a zero, level of mineral fertilizer. These findings support the inclusion of seaweed biostimulants in nutrient management programmes for cowpea and related legumes as a means of improving rhizosphere fertility and potentially reducing dependence on inorganic fertilizer inputs; further work incorporating crop nutrient uptake would help to fully establish the agronomic and economic value of this practice.

References

1. Alam MZ, Braun G, Norrie J, Hodges DM. Effect of *Ascophyllum* extract application on plant growth, fruit yield and soil microbial communities of strawberry. *Canadian Journal of Plant Science*. 2013; 93:23-36.
2. Banjare L, Banwasi R, Jataw GK, Shrivastav LK. Effect of seaweed extract on yield and nutrient uptake of rice in a vertisol. *The Pharma Innovation Journal*. 2022;11(3):2193-2198.
3. Chen CL, Song WL, Sun L, Qin S, Ren CG, Yang JC, *et al*. Effect of seaweed extract supplement on rice rhizosphere bacterial community in tillering and heading stages. *Agronomy*. 2022;12(2):342.
4. Circuncisão AR, Catarino MD, Cardoso SM, Silva AM. Minerals from macroalgae origin: health benefits and risks for consumers. *Marine Drugs*. 2018;16(11):400.
5. Deepana P, Sathiya Bama K, Santhy P, Sivasankari Devi T. Effect of seaweed extract on rice (*Oryza sativa* var. ADT53) productivity and soil fertility in Cauvery delta zone of Tamil Nadu, India. *Journal of Applied and Natural Science*. 2021;13(3):1111-1120.
6. De Sosa LL, Navarro-Fernández CM, Panettieri M, Madejón P, Pérez-de-Mora A, Madejón E. Application of seaweed and pruning residue as organic fertilizer to increase soil fertility and vine productivity. *Soil Use and Management*. 2023;39(2):794-804.
7. Du Jardin P. Plant biostimulants: definition, concept, main categories and regulation. *Scientia Horticulturae*. 2015; 196:3-14.
8. Hussain HI, Kasinadhuni N, Arioli T. The effect of seaweed extract on tomato plant growth, productivity and soil. *Journal of Applied Phycology*. 2021;33(2):1305-1314.
9. Jackson ML. *Soil Chemical Analysis*. New Delhi: Prentice-Hall of India Private Limited; 1973.
10. James VCX, Thiraviam AGP, Al-Dosary MA, Hatamleh AA, Bukhari NA, Arokiyaraj S, *et al*. Evaluation of nutrient composition and biostimulant properties of seaweeds for improving soil microbial population and tomato plant growth. *BioResources*. 2025;20(1):1431-1451.
11. Karthikeyan K, Shanmugam M. The effect of a potassium-rich seaweed extract on quality parameters of sugarcane. *Journal of Applied Phycology*. 2017; 29:3245-3252.
12. Margal PB, Thakare RS, Kamble BM, Patil VS, Patil KB, Titirmare NS. Effect of seaweed extracts on crop growth and soil: a review. *Journal of Experimental Agriculture International*. 2023;45(9):9-19.
13. Nivetha N, Shukla PS, Nori SS, Kumar S, Suryanarayan S. A red seaweed *Kappaphycus alvarezii*-based biostimulant (AgroGain®) improves the growth of *Zea mays* and impacts agricultural sustainability by beneficially priming rhizosphere soil microbial community. *Frontiers in Microbiology*. 2024; 15:1330237.
14. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939. Washington, DC: United States Department of Agriculture; 1954.
15. Panse VG, Sukhatme PV. *Statistical methods for agricultural workers*. 4th ed. New Delhi: Indian Council of Agricultural Research, Publication and Information Division; 1985.
16. Peñalver R, Lorenzo JM, Ros G, Amarowicz R, Pateiro M, Nieto G. Seaweeds as a functional ingredient for a healthy diet. *Marine Drugs*. 2020;18(6):301.
17. Pérez-Oñate CJ, Nicolau MCM, Ferreira TC, Broetto F, Stadnik MJ, *et al*. Crop yield responses to seaweed extract-based biostimulants depend on application strategy, formulation, and extraction methods: a meta-analysis. *Frontiers in Plant Science*. 2026; 17:1803269.
18. Rathore SS, Chaudhary DR, Boricha GN, Ghosh A, Bhatt BP, Zodape ST, *et al*. Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions. *South African Journal of Botany*. 2009;75(2):351-355.
19. Singh D. Comparative analysis of fodder cowpea (*Vigna unguiculata* L.) varieties for seed yield and nutrient content. *Forage Research*. 2023;49(2):224-230.
20. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. 1956; 25:259-260.
21. Supriya, Singh M, Meena RK, Saxena A, Kumar R, Babu CRT. Seaweed as bio-stimulant for advancing crop sustainability: a review. *Journal of Indian Fisheries Association*. 2023;50(4):40-49.
22. Vicente TFL, Félix C, Félix R, Valentão P, Lemos MFL. Seaweed as a natural source against phytopathogenic bacteria. *Marine Drugs*. 2023;21(1):23.
23. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*. 1934;37(1):29-38.
24. Wang MP, Chen L, Li YT, Chen L, Liu ZY, Wang XJ, Yan PS, Qin S. Responses of soil microbial communities to a short-term application of seaweed fertilizer revealed by deep amplicon sequencing. *Applied Soil Ecology*. 2018;125:288-296.
25. Yakhin OI, Lubyanov AA, Yakhin IA, Brown PH. Biostimulants in plant science: a global perspective. *Frontiers in Plant Science*. 2017; 7:2049.