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Short communication

Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions

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Abstract

A field experiment was conducted during the rainy (*kharif*) season in Indian in 2006 to study the effects of foliar applications of different concentrations of seaweed extract (prepared from *Kappaphycus alvarezii*) on nutrient uptake, growth and yield of soybean [*Glycine max* (L.) Merr.] grown under rainfed conditions without the application of chemical fertilizers. The foliar spray was applied twice at seven concentrations (0; 2.5; 5; 7.5; 10; 12.5 and 15% v/v) of seaweed extract. Foliar applications of seaweed extract significantly enhanced yield parameters. The highest grain yield was recorded with applications of 15% seaweed extract, followed by 12.5% seaweed extract that resulted in 57% and 46% increases respectively compared to the control. The maximum straw yield was also achieved with 15% seaweed extract application. Improved nutrient uptake (N, P, K and S) was also observed with seaweed extract applications. Thus, under rainfed soybean production, foliar applications of seaweed extracts could be a promising option for yield enhancement.

Keywords: Marine bioactive substances; Nutrient uptake; Quality; Seaweed extract; Soybean; Yield

1. Introduction

Any improvement in agricultural system that results in higher production should reduce the negative environmental impact of agriculture and enhance the sustainability of the system. One such approach is the use of biostimulants, which can enhance the effectiveness of conventional mineral fertilizers. Marine bioactive substances extracted from marine algae are used in agricultural and horticultural crops, and many beneficial effects, in the terms of enhancement of yield and quality have been reported (Blunden, 1991; Crouch and Van Staden, 1994). Liquid extracts obtained from seaweeds have recently gained importance as foliar sprays for many crops including various grasses, cereals, flowers and vegetable species (see Crouch and Van Staden, 1994 for a comprehensive list). Seaweed extracts contains major and minor nutrients, amino acids, vitamins, cytokinins, auxin and abscisic acid like growth promoting substances (Mooney and Van Staden, 1986) and have been reported to stimulate the growth and yield of plants (Rama Rao, 1991), develop tolerance to environment stress (Zhang and Schmidt, 2000; Zhang et al., 2003), increase nutrient uptake from soil (Verkleij, 1992; Turan and Köse, 2004) and enhance antioxidant properties (Verkleij, 1992).

The beneficial effect of seaweed extract application is as a result of many components that may work synergistically at different concentrations, although the mode of action still remains unknown (Fornes et al., 2002). In recent years, use of seaweed extracts have gained in popularity due to their potential use in organic and sustainable agriculture (Russo and Beryln, 1990), especially in rainfed crops, as a means to avoid excessive fertilizer applications and to improve mineral absorption. Unlike, chemical fertilizers, extracts derived from seaweeds are biodegradable, non-toxic, non-polluting and non-hazardous to humans, animals and birds (Dhargalkar and Pereira, 2005).

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Soybean, *Glycine max* (L.) Merr., is one of the richest sources of protein and can be a potential source of protein-rich food for the majority of Indian population. This crop dominantly supplies the edible vegetable oil and high-protein feed supplements for livestock to the world. Other fractions and derivatives of the seed have substantial economic importance in a wide range of industrial, food, pharmaceutical, and agricultural products (Smith and Huyser, 1987). The main objective of this study is to evaluate the application of different concentrations of seaweed extract in enhancing the growth, yield, quality and nutrient uptake of soybean (*G. max*) grown in fields, under rainfed conditions.

2. Materials and methods

2.1. Preparation of liquid seaweed extract

The seaweed extract used in this study was obtained from *Kappaphycus alvarezii* (Doty) a red algae belonging to the family Solieraceae. The algae was handpicked from the coastal area of Rameswaram, T. N., India during September 2005. It was washed with seawater to remove unwanted impurities and transported to our field station at Mandapum, Rameswaram. Here samples were thoroughly washed using tap water. After that, fresh seaweed samples were homogenized by grinder with stainless steel blades at ambient temperature, filtered and stored (Eswaran et al., 2005). The liquid filtrate was taken as 100% concentration of the seaweed extract and further diluted as per the treatments. The nitrogen (N) content of seaweed extract (100% concentrate) was determined by taking 20 mL of filtrate which was oxidized and decomposed by concentrate sulphuric acid (10 mL) with digestion mixture (K_2SO_4:$CuSO_4$ = 5:1) heated at 400 °C temperature for two and half hours as described in the semi-micro Kjeldahl method (AOAC International, 1995, method No. Ba 4b-87(90)), and other nutrient elements were analysed by ICP-OES (inductively coupled plasma-optical emission spectroscopy), after wet digestion of filtrate (20 mL) with HNO_3–$HClO_4$ (10:4) di-acid mixture (20 mL) and heated at 100 °C for 1 h and then raise the temperature to about 150 °C (Richards, 1954).

2.2. Experimental site

The field experiment was conducted during the rainy season of 2006 on Inceptisol at ICAR Research Complex, N. E. H. region, Jharnapani Centre, Nagaland, India (Foothills of Nagaland). The soil of the site was clay loam with $pH_{(1:2.5::soil:water)}$ 4.8, non-saline [$EC_{(1:2.5\ soil:water)}$ 0.3 dS/m], and with cation exchange capacity of 13.57 cmol (p^+)/kg. The experimental soil contained 1.5% organic carbon, available nitrogen (N; 296 kg/ha), available phosphorus (P; 27 kg/ha) and available potassium (K; 278.16 kg/ha). The climate of the region is humid subtropical. The experimental site is located at 25.27° N latitude, 93.95° E longitude and 250 m above mean sea level.

2.3. Experimental design and treatments

The experiment comprised of seven treatments, *viz*, 0 (control, water spray), 2.5; 5; 7.5; 10; 12.5 and 15% (volume/volume; v/v) of seaweed extract in water. Two sprays of *K. alvarezii*-derived extract were applied, one at the seedling stage (30 days after sowing) and the second at the flowering stage (60 days after sowing). The total spray volume was 650 L/ha in each application. The treatments were distributed in a randomized block design with three replications. The net plot size was 6 m × 0.90 m.

2.4. Crop management

Farm yard manure was applied at the rate of 10 tonnes/ha on fresh weight basis before sowing of the soybean crop. No chemical fertilizers were applied. Seeds treatment were done with fungicide thiram (1-(dimethylthiocarbamoyldisulfanyl)-N, N-dimethyl-methanethioamide) + carbendazim (methyl N-(1H-benzoimidazol-2-yl)carbamate) in 2:1 ratio at 3 g/kg seed for control of collar rot, charcoal rot and leaf spot. The seeds of soybean (var. JS-335) were manually sown in July 2006 in rows, 45 cm apart at a depth of 4–5 cm and keeping 15 cm plant intervals. Phorate 10G (O,O-diethyl S-ethylthiomethyl phos-phorodithioate) at10 kg/ha was applied at the time of sowing for control of stem fly and spray of Quinalphos 25EC (O,O-diethyl-O-2-quinoxalinyl phos-phorothioate) at 1.5 L/ha and Mono-crotophos 36SL [(E)-dimethyl 1-methyl-3-(methylamino-3-oxo 1-propenyl phosate] at 0.8 L/ha were done at seedling stage to control blue beetle and girdle beetle respectively. Hand weeding was used as and when required to remove weeds. Irrigation was not applied as the crop was totally rainfed. The total rainfall received during the crop period i.e., July, August, September and October 2006 was 259, 95, 248 and 85 mm respectively. The Crop was harvested at physiological maturity in October, 2006.

2.5. Plant sampling

At maturity, soybean grain and straw samples were collected from each plot, oven dried at 70 °C to constant weight and ground to pass through a 0.5 mm sieve for chemical analysis. The nitrogen (N) content was determined by the semi-micro Kjeldahl method (AOAC International, 1995, method No. Ba 4b-87(90)), after the plant tissues (0.2 g) were oxidized and decomposed by concentrate sulphuric acid (10 mL) with

Table 1
Chemical constituents of *K. alvarezii* seaweed extract.

Constituents	Concentration
Nutrients	
Nitrogen (%) [a]	0.03
Phosphorus (mg/L)	33.99
Potassium (%)	1.97
Sodium (%)	0.51
Calcium (mg/L)	460.11
Magnesium (mg/L)	581.20
Sulphur (%)	0.06
Copper (mg L^{-1})	0.30
Iron (mg L^{-1})	10.59
Manganese (mg L^{-1})	2.50
Zinc (mg L^{-1})	0.62

[a] weight by volume.

Table 2
Effect of seaweed extract on yield contributing characters of soybean.

Treatment (%)	Plant height (cm)	No. of plants m^{-2}	No. of pods $plant^{-1}$	No. of grains pod^{-1}	No. of branches $plant^{-1}$	Test weight (g)	Straw yield (q ha^{-1} [a])	Grain yield (q ha^{-1})	Harvest index
0	69.88d	17.63f	126.48e	2.87c	4.96e	129.23d	52.38b	13.39d	0.20d
2.5	72.11cd	18.77ef	131.15e	3.21c	5.34e	129.86d	52.35b	14.80cd	0.22cd
5.0	73.08cd	20.31de	135.10de	3.20c	5.92de	131.01d	53.77b	14.92cd	0.21cd
7.5	74.99bcd	22.53cd	147.56cd	3.60b	6.57cd	135.21c	55.72a	16.35bc	0.23c
10.0	76.80abc	24.06bc	161.36bc	3.77b	6.90bc	136.90c	56.97a	17.18b	0.23bc
12.5	80.46ab	25.30ab	174.68b	3.78b	7.56ab	141.65b	55.99a	19.60a	0.26ab
15.0	81.60a	26.70a	206.85a	4.20a	8.01a	146.48a	55.56a	21.09a	0.27a

[a] quintal per hectare (1 quintal = 100 kg); Different letters in a single column show statistically significant differences for $P < 0.05$.

digestion mixture (K_2SO_4:$CuSO_4$ = 5:1) heated at 400 °C temperature for two and half hours. Phosphorus (P) content was determined by the vanado-molybdate yellow method (Jackson, 1973), Potassium (K) content by flame photometry (Jackson, 1973) and sulphur (S) concentration by ICP-OES after wet digestion of plant tissues (1.0 g) with HNO_3–$HClO_4$ (10:4) di-acid mixture (20 mL) and heated at 100 °C for 1 h and then raise the temperature to about 150 °C until the contents become colourless but not allowed to dry, made the volume 100 mL and filtered through Whatman No. 42 filter paper (Richards, 1954).

2.6. Statistical analysis

Data were analysed using analysis of variance (ANOVA) following randomized block design (Gomez and Gomez, 1984). Differences were considered significant at 5% level of probability.

3. Results and discussion

3.1. Effect of seaweed extract on yield and yield parameters of soybean

The chemical constituents of the of *K. alvarezii* extract are presented in Table 1. The use of seaweed extract increased all the growth parameters measured for soybean with 15% treatment being significantly better (Table 2). In general, a gradual increase in plant height was observed with increasing seaweed extract application. Plant height was significantly higher at 10% and higher concentrations of the seaweed extract. Numbers of plant per square meter increased significantly compared to the control concentrations of treatment of 7.5% and above. The highest number of pods per plant, test weight (weight of 1000 grains) and number of grains per pod were observed at 15% seaweed extract which was significantly higher over all other treatments. Plant height, number of pods per plant, number of grains per plant, number of branches per plant and test weight were not significantly affected by foliar applications of seaweed extract up to 5% concentration.

Our findings coincide with those of earlier studies carried out on marigold (Aldworth and Van Staden, 1987; Russo et al., 1994) where there was an increase in vegetative growth by the application of seaweed extract. Similar results were also observed in *Cajanus cajan* (L.) Millsp. (Mohan et al., 1994) and *Vigna sinensis* L. (Sivasankari et al., 2006). The increased growth of these crops may be due to the presence of some growth promoting substances present in the seaweed extract (Mooney and Van Staden, 1986; Blunden, 1991). In addition, the growth enhancing potential of the seaweed extract might be attributed to the presence of macro and micronutrients.

The test crop under present investigation was grown under rainfed conditions, and thus it may have faced water stress conditions. Exogenous application of seaweed extract has already been shown to enhance antioxidants status of Kentucky bluegrass (Zhang and Schmidt, 1999), tall fescue and creeping bentgrass (Zhang and Schmidt, 2000).

Straw yield was observed highest at 15%, which was statistically similar to 7.5, 10 and 12.5% of seaweed extract. Application of 7.5, 10, 12.5 and 15% of seaweed extract significantly increased the straw yield of soybean by 6.37, 8.76, 6.89 and 6.07% respectively over the control. The effect of the treatments on grain yield also depicted a similar trend, where highest yield was recorded with a 15% followed by 12.5% application (57.49 and 46.34% respectively) increase over control.

Table 3
Effect of seaweed extract on N, P, K and S uptake by soybean.

Treatment (%)	Grain uptake (kg ha^{-1})				Straw uptake (kg ha^{-1})			
	N	P	K	S	N	P	K	S
0	79.71e	8.66c	23.41d	4.17b	49.41a	21.15d	101.16ab	8.20a
2.5	83.20de	9.15c	25.17d	3.89b	42.26a	20.23cd	86.27d	7.54a
5.0	81.91de	9.68bc	26.25cd	5.82ab	43.42a	22.68bc	104.11ab	8.84a
7.5	94.45cd	9.88bc	30.43bc	6.04ab	50.26a	27.35a	108.07a	10.25a
10.0	104.09bc	10.87b	30.32bc	6.85a	46.55a	24.99ab	97.68bc	8.70a
12.5	119.02a	13.32a	31.20ab	7.11a	53.19a	20.27cd	89.91cd	8.25a
15.0	108.33ab	13.96a	34.82a	8.08a	48.26a	18.60d	84.22d	8.98a

Different letters in a single column show statistically significant differences for $P < 0.05$.

However, both treatments were not significantly different, harvest index [Economic yield (grain)/Biological yield (grain + straw)] of soybean also followed similar trend to yield.

In this study increased vegetative growth, number of pods per plant, number of grains per pod, and test weight due to seaweed extract application resulted in greater overall production of grain yield. Similarly, Rama Rao (1991) obtained increased yield and improvement in the quality of *Zizyphus mauritiana* Lamk. with foliar applications of seaweed extract. Further, our findings also coincide with those of earlier studies made by Mohan et al. (1994) and Rajkumar and Subramanian (1999) who noted increased germination and enhanced seedling growth of the plants [maize (G-5), cholam (CSH-9), ragi (CO-9), kambu (KM-2) and *C. cajan* L. (CO-6)] by seaweed extract applications.

3.2. Effect of seaweed extract on nutrient uptake of soybean

The use of the seaweed extract increased significantly N, P and K uptake by grains at higher concentrations (7.5% and above) and reached maximum at 12.5%, 15% and 15% application rate respectively of the seaweed extract compared with control (Table 3). Sulphur uptake by grains was significantly increased at 10% and above levels of seaweed extract applications. Nitrogen and S uptake by straw were not significantly influenced by seaweed extract applications whereas, P and K affected significantly. Highest P uptake by straw was observed at 7.5% and followed by 10% concentrations of the seaweed extract. Our results confirm those previously reported by Crouch et al. (1990) who noted increased uptake of Mg, K and Ca in lettuce with seaweed concentrate application. Turan and Köse (2004), Nelson and Van Staden (1984), and Mancuso et al. (2006) also observed increased uptake of N, P, K and Mg in grapevines and cucumber with application of seaweed extract. The presence of marine bioactive substances in seaweed extract improves stomata uptake efficiency in treated plants compared to non-treated plants (Mancuso et al., 2006).

Biostimulants, even those containing minerals, are not able to supply all the essential nutrients in the quantities required by plants (Schmidt et al., 2003) but may enhance root growth of plant subjected to stress possibly by increasing the antioxidant defense system (Zhang and Schmidt, 1997, 1999, 2000). In addition to proper mineral fertilization, biostimulants can enhance the effectiveness of fertilizers as well as nutrient utilization from soil (Frankenberger and Arshad, 1995) as reported in our study with increased uptake of nutrients in soybean.

In conclusion, the *K. alvarezii* derived seaweed extract is effective in increasing the growth parameters (plant height, number of plants per square meter, number of pods per plant, number grains per pod, number of branches per plant and test weight), yield and enhancing nutrient uptake by the plants.

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