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Effect of seaweed extract on growth, yield and quality in different field crops: A review

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Abstract
The excessive use of chemicals and inorganic fertilizers by farmers to increase crop yield is detrimental to the environment and human health. Application of bio-stimulants such as seaweed extract (SWE) in agriculture could be an effective and eco-friendly alternative to inorganic fertilizers. Bio-stimulants are natural organic degradable substances. Their application serves as a source of nutrition for crops, possibly improving growth and productivity when applied in combination with the fertilizers. The beneficial effects of seaweed on soil and crops have been empirically observed by farmers and confirmed by scientific studies. Foliar application of seaweed significantly enhanced the growth parameters, yield components, quality parameters in different field crops when compared to control.

Keywords: Bio-stimulants, eco-friendly, inorganic fertilizers, productivity, seaweed extract

Introduction
A marine algae (seaweed) is one of the renewable and economically valuable sea wealth. Seaweeds are marine algae that are macroscopic and found attached at the bottom of shallow and deep coastal waters and also grows on solid substrates like rocks, pebbles and dead corals. Application of seaweed extract (SWE) in agriculture could be an effective and eco-friendly alternative to inorganic fertilizers. Algae, particularly the seaweeds, are used as organic bio-fertilizers and soil stabilizers resulting in less nitrogen and phosphorous runoff from farm lands. The addition of seaweed species leads to chemical changes in soil fertility indicator of soils by improving its organic matter content, neutralize the soil reactions and reduces the C: N ratio in both sandy and clay soils. Seaweed liquid fertilizer and powdered algal manure have been used as bio-stimulants on cereals and pulses. Usage of seaweed as a manure is a common practice in coastal areas throughout the world. Seaweed extract (SWE) collected from *Ulva lactuca*, *Ascophyllum nodosum*, *Sargassum liebmannii etc.*, is the most commonly used soil amendment. Generally, all these could cause a synergistic effect on plant growth by enhancing seed germination, contributing to vegetative growth and modulating the reproductive behavior in plants. The undesirable effects of inorganic fertilizers on the environment have stimulated studies on new natural resources of fertilizers, bio-stimulants and soil amendments. Seaweed biomass represents a substitute for conventional inorganic fertilizers. The beneficial outcome of SWE application on crop plants is due to various components that may work synergistically at different concentrations. Moreover, SWE is readily biodegradable, free from toxins, non-polluting and non-hazardous. Extracts of seaweed enhance antioxidant properties, contains amino acids, vitamins, cytokinins, auxins, abscisic acid, major and minor nutrients, that act as growth promoting substances which promote growth, yield and develop tolerance against environmental stress in plants.

Effect of Seaweed Extract on Growth Parameters
Seaweed nano powder treated seeds recorded higher germination percentage in pigeonpea (Ambika and Sujatha, 2016) [2].

Plant population was found non-significant with application of seaweed extract @ 500 ml ha-1 in soyabean (Guerreiro *et al*., 2017) [13].

Application of 15% concentration of seaweed extract recorded higher plant height compared to control in soybean (Rathore *et al.,* 2009) [21]. Foliar spray of 0.4% concentration of seaweed extract resulted higher plant stature in greengram (Kavipriya *et al.,* 2011) [15]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in increased plant height in greengram (Pramanick *et al.,* 2013 and Basavaraja *et al.,* 2018) [19, 3]. Foliar spray of 1 ml of seaweed extract L^{-1} increased plant height by 41.3% compared to untreated plants in chickpea (Boghdady *et al.,* 2016) [4]. Seed treatment with combined application of 15% seaweed extract resulted in higher plant height in hybrid maize (Dilvaranaik *et al.,* 2017) [7]. Application of seaweed extract @ 500 ml ha^{-1} at flowering stage resulted in higher plant height in soyabean (Guerreiro *et al.,* 2017) [13]. Soil application of seaweed extract gel @ 12.5 kg ha^{-1} + foliar spray of seaweed extract liquid @ 0.5% at tillering and panicle initiation stages resulted in significantly higher plant height in rice (Deepana *et al.,* 2021) [6]. Application of 2.0% of *Ascophyllum nodosum* to seeds resulted in higher plant height compared to control in *kabuli* chickpea (Kurakula and Rai, 2021) [17]. Combined application of vermicompost, *rhizobium,* PSB and seaweed extract resulted in significant increase of plant height compared to without seaweed application treatment in French bean (Rai *et al.,* 2021) [17]. Foliar application of bio-stimulants like Bio-zyme $crop^{+}$ and Quantis resulted in significant increase in plant height in blackgram (Vishwanatha *et al.,* 2022) [24].

Higher leaf area was recorded with application of seaweed liquid fertilizer @ 1.5% in chickpea (Gurusaravanan *et al.,* 2011) [14]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in higher leaf area index in greengram (Pramanick *et al.,* 2013) [19]. Foliar application of seaweed extract @ 20% significantly increased the leaf area of tomato plants compared to control (Sutharsan *et al.,* 2014) [23]. Application of *Kappaphycus* sap @ 10% + RDF resulted in significant increase in leaf area index of maize compared to control (Garai *et al.,* 2019) [10]. Soil application of seaweed extract gel @ 12.5 kg ha^{-1} + foliar spray of seaweed extract liquid @ 0.5% at tillering and panicle initiation stages resulted in higher leaf area index in rice (Deepana *et al.,* 2021) [6].

Application of 15% concentration of seaweed extract recorded significantly higher number of branches $plant^{-1}$ in soyabean (Rathore *et al.,* 2009) [21]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted significant increase in number of branches $plant^{-1}$ compared to control in greengram (Pramanick *et al.,* 2013) [19]. Higher number of branches $plant^{-1}$ were registered with the treatment of 1 ml of seaweed extract/L compared to untreated plants in chickpea (Boghdady *et al*., 2016) [4]. Application of 2.0% of *Ascophyllum nodosum* to seeds resulted in significantly higher number of branches $plant^{-1}$ compared to control in *kabuli* chickpea (Kurakula and Rai, 2021) [17]. Combined application of *rhizobium* and seaweed extract resulted in significant increase of number of branches $plant^{-1}$ in french bean (Rai *et al.,* 2021) [17]. Foliar application of bio-stimulants like Bio-zyme $crop^{+}$ and Quantis resulted in significant increase in number of branches $plant^{-1}$ compared to control in blackgram (Vishwanatha *et al.,* 2022) [24]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in higher dry matter production in greengram (Pramanick *et al.,* 2013) [19]. Seaweed nano powder treated seeds resulted in higher dry matter production in pigeonpea (Ambika and Sujatha, 2016) [2]. Application of bio-stimulants like Algex made from *Ascophyllum nodusum* significantly improved the dry matter production compared to control in red clover (Godlewska and Ciepiela, 2020) [12]. Soil application of seaweed extract gel @ 12.5 kg ha^{-1} + foliar spray of seaweed extract liquid @ 0.5% at tillering and panicle initiation stages resulted in higher dry matter production in rice (Deepana *et al.,* 2021) [6]. Foliar application of bio-stimulants like Bio-zyme $crop^{+}$ and Quantis resulted in significant increase in dry matter production in blackgram (Vishwanatha *et al.,* 2022) [24].

Effect of seaweed extract on root growth parameters

Higher number of root nodules $plant^{-1}$ were recorded in the treatment applied with seaweed liquid fertilizer of *Turbinaria decurrens* @ 1.50% concentration in chickpea (Gurusaravanan *et al.,* 2011) [14]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in significantly higher number of root nodules $plant^{-1}$ in greengram (Pramanick *et al.,* 2013) [19]. Combined application of *rhizobium,* PSB and seaweed extract resulted in significant increase of number of root nodules $plant^{-1}$ in French bean (Rai *et al.,* 2021) [17]. Foliar application of bio-stimulants like Bio-zyme $crop^{+}$ and Quantis resulted in significant increase in number of root nodules $plant^{-1}$ compared to control in blackgram (Vishwanatha *et al.,* 2022) [24]. Higher root length was recorded in the treatment applied with seaweed liquid fertilizer @ 1.5% concentration in chickpea (Gurusaravanan *et al.,* 2011) [14]. Higher root length was registered in the treatment of 0.4% concentration of seaweed extract in greengram (Kavipriya *et al.,* 2011) [15]. Application of seaweed extract at 0.5% resulted in increase of root length in onion (Abbas *et al.,* 2020) [1]. Soil application of seaweed extract gel @ 12.5 kg ha^{-1} + foliar spray of seaweed extract liquid @ 0.5% resulted in significantly higher root length in rice (Deepana *et al.,* 2021) [6]. Significantly higher dry weight of roots was recorded in the treatment applied with seaweed liquid fertilizer @ 0.5% in chickpea (Gurusaravanan *et al.,* 2011) [14]. Higher dry weight of roots was recorded in the treatment of 0.4% concentration of seaweed extract in greengram (Kavipriya *et al.,* 2011) [15]. Foliar application of seaweed extract @ 20% concentration significantly increased dry weight of tomato plants compared to control (Sutharsan *et al.,* 2014) [23].

Effect of Seaweed Extract on Yield Attributes

Application of 15% concentration of seaweed extract recorded significantly higher number of pods $plant^{-1}$ in soyabean (Rathore *et al.,* 2009) [21]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in increased number of pods $plant^{-1}$ in greengram (Pramanick *et al.,* 2013) [19].

Significantly higher number of pods $plant^{-1}$ were registered at the treatment of 1 ml of seaweed extract L^{-1} (untreated plants) in chickpea (Boghdady *et al.,* 2016) [4]. Application of seaweed extract Ascomaxx @ 500 ml ha^{-1} twice at flowering stage and pod formation stages resulted in significantly higher number of pods $plant^{-1}$ in soyabean (Guerreiro *et al.,* 2017) [13].

Application of 2.0% of *Ascophyllum nodosum* to seeds resulted in increased number of pods $plant^{-1}$ in *kabuli* chickpea (Kurakula and Rai, 2021) [17]. Combined application of *rhizobium,* PSB and seaweed extract resulted in significant increase of number of pods $plant^{-1}$ in French bean (Rai *et al.,* 2021) [17]. Foliar application of bio-stimulants like Bio-zyme $crop^{+}$ and Quantis resulted in significant increase in number of pods per $plant^{-1}$ in blackgram (Vishwanatha *et al.,* 2022) [24]. Application of 15%

concentration of seaweed extract recorded higher number of grains pod^{-1} in soyabean (Rathore *et al.*, 2009) [21]. Application of 15% *Gracillaria* sap + recommended dose of fertilizer (RDF) resulted in increased number of seeds pod^{-1} in greengram (Pramanick *et al.*, 2013) [19]. Significantly higher number of seeds pod^{-1} were recorded with the treatment of 1 ml of seaweed extract/L in chickpea (Boghdady *et al.*, 2016) [4]. Application of *Kappaphycus* sap @ 10% + RDF resulted in significant increase in number of seeds pod^{-1} compared to control in garden pea (Garai *et al.*, 2019) [10]. Application of 2.0% of *Ascophyllum nodosum* to seeds resulted in significantly higher number of seeds plant^{-1} in *kabuli* chickpea (Kurakula and Rai, 2021) [17]. Application of 15% concentration of seaweed extract recorded significantly higher test weight in soyabean (Rathore *et al.*, 2009) [21]. Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in higher hundred seed weight in greengram (Pramanick *et al.*, 2013) [19]. Higher weight of 100 seeds was recorded at the treatment of 0.75 ml of seaweed extract/L in chickpea (Boghdady *et al.*, 2016) [4]. Combined application of 15% *Gracillaria* sap + 10% *Gracillaria* sap resulted in significantly higher weight of 100 grains compared to control in hybrid maize (Dilvaranaik *et al.*, 2017) [7]. Application of 10% *Gracillaria edulis* sap + RDF resulted in significantly increased the hundred seed weight compared to control (water spray + RDF) in maize (Basavaraja *et al.*, 2018) [3]. Soil application of seaweed extract gel @ 12.5 kg ha^{-1} + foliar spraying of seaweed extract liquid @ 0.5% at tillering and panicle initiation stages resulted in significantly higher weight of 1000 grains in rice (Deepana *et al.*, 2021) [6].

Effect of seaweed extract on yield

Application of 15% *Kappaphycus* sap + recommended dose of fertilizer (RDF) resulted in an increase of seed yield by 38.97% compared to control in greengram (Pramanick *et al.*, 2013) [19]. Application of 15% *Kappaphycus sap* + recommended dose of fertilizer (RDF) resulted in increase of seed yield by 49.2% compared to control in blackgram (Dwivedi *et al.*, 2015) [9]. Higher seed yield was recorded at the treatment of 1 ml of seaweed extract L^{-1} compared to untreated plants in chickpea (Boghdady *et al.*, 2016) [4]. Combined application of 15% seaweed extract resulted in higher seed yield compared to control in hybrid maize (Dilvaranaik *et al.*, 2017) [7]. Application of 10% *Gracillaria edulis* sap + RDF resulted in significant increase of seed yield compared to control in maize (Basavaraja *et al.*, 2018). Application of seaweed extract at 0.5%, 1%, 2% and 3% concentration resulted in significant increase of seed yield of onion (Abbas *et al.*, 2020) [1].

Spraying of seaweed extract @ 7.5% resulted in significant increase in seed yield of wheat (Kumar *et al.*, 2021) [16]. Application of 2.0% of *Ascophyllum nodosum* resulted in significantly higher seed yield chickpea (Kurakula and Rai, 2021) [17]. Combined application of *rhizobium*, PSB and seaweed extract resulted in significant increase of seed yield in french bean (Rai *et al.*, 2021) [17]. Foliar application of bio-stimulants like Bio-zyme crop^{+} and Quantis resulted in significant increase in seed yield compared to control in blackgram (Vishwanatha *et al.*, 2022) [24]. Application of 15% concentration of seaweed extract registered significantly higher harvest index of 0.27% compared to control in soyabean (Rathore *et al.*, 2009) [21]. Application of *Kappaphycus* sap @ 10% + RDF resulted in significant increase in harvest index of maize (Garai *et al.*, 2019) [10]. Soil application of seaweed extract gel @ 12.5 kg ha^{-1} resulted in significantly higher harvest index of (44%) in rice (Deepana *et al.*, 2021) [6]. Application of seaweed extract @ 4 ml/liter of water at tillering and heading stages gave significantly higher harvest index in wheat (Sarita *et al.*, 2021) [22].

Effect of seaweed extract on quality parameters

Significantly higher crude protein content of seed was recorded at the treatment of 1 ml of seaweed extract/L in chickpea (Boghdady *et al.*, 2016) [4]. Application of bio-stimulants like Algex made from *Ascophyllum nodusum* significantly improved the protein content in plants in red clover (Godlewska and Ciepiela, 2020) [12]. Combined application of *rhizobium*, PSB and seaweed extract resulted in significant increase of protein content in seeds in French bean (Rai *et al.*, 2021) [17].

Effect of seaweed extract on nutrient uptake

Application of 15% concentration of seaweed extract increased the uptake of nitrogen, phosphorus and potassium by grains in soyabean (Rathore *et al.*, 2009) [21]. Use of the seaweed extracts significantly increased N, P and K uptake by seeds and stover of greengram compared to sole application of chemical fertilizers (Pramanick *et al.*, 2013) [19]. Application of 10% *Kappaphycus alvarezii* sap + RDF and 10% *Gracillaria edulis* + RDF resulted in increased uptake of N, P and K compared to the treatment of water spray + RDF in maize (Basavaraja *et al.*, 2018) [3]. N, P and K uptake was higher by the plants treated with 15% *Gracillaria sp.* sap + RDF treatment in wheat (Ghosh *et al.*, 2020) [11]. Soil application of seaweed extract gel @ 25 kg ha^{-1} resulted in increased uptake of N, P, K, Fe, Zn, Cu and Mn compared to control in rice (Deepana *et al.*, 2021) [6]. N, P and K content were significantly higher in the treatment of 1 ml of seaweed extract/L in chickpea (Boghdady *et al.*, 2016) [4]. Application of seaweed extract at 0.5% concentration resulted in significant increase of N, P and K content in onion (Abbas *et al.*, 2020) [1]. Combined application of seaweed extract and *rhizobium* resulted in significant increase of micronutrients *viz.*, Fe, Cu, Zn and Mn in Amaranthus (Ngoroyemoto *et al.*, 2020) [18]. Soil application of seaweed extract gel @ 25 kg ha^{-1} resulted in non-significant effect on soil pH, EC but significant increase of organic carbon content of soil compared to control in rice (Deepana *et al.*, 2021) [6].

Effect of Seaweed Extract on Soil Microbial Properties and Soil Enzymes

Application of seaweed fertilizer resulted in significant increase of microbial population and dehydrogenase activity in maize (Zhou *et al.*, 2019 and Chen *et al.*, 2020) [25, 5]. Combined application of seaweed extract and *rhizobium* resulted in significant increase of microbial population in Amaranthus (Ngoroyemoto *et al.*, 2020) [18].

Effect of Seaweed Extract on Economics

Significantly higher gross and net returns and benefit - cost ratio by application of 15% *Kappaphycus* sap along with 75% RDF in greengram (Pramanick *et al.*, 2013) [19]. Foliar application of 15% *Kappaphycus sap* + recommended dose of fertilizer (RDF) significantly increased the monetory returns and B: C ratio in blackgram (Dwivedi *et al.*, 2014) [8]. Application of *Kappaphycus* sap @ 10% + RDF resulted in significant increase in gross and net returns and B: C ratio of maize (Garai *et al.*, 2019) [10]

Combined application of *rhizobium*, PSB and seaweed extract resulted in significant increase of net returns and B: C ratio compared to without seaweed application in French bean (Rai *et al.*, 2021) [17]. Application of seaweed extract @ 4 ml/liter of

water at tillering and heading stages gave significantly higher B: C ratio compared to control in wheat (Sarita *et al.*, 2021) [22].

Conclusion

The application of seaweed extract to the crop plants was more effective in promoting vegetative growth. This stimulated the release of macro- and micronutrients and other organic compounds, which had a dual effect on growth parameters (plant height, leaf area index, chlorophyll content, root length *etc*.,). It increases the availability of inorganic nutrients, and substrate porosity, all of which improved the root system development, nutrient uptake and assimilation, and chlorophyll synthesis, and consequently benefited the morphological attributes of the plants. It could be suggest that, application of sea weed extract is helps in promote vegetative growth, yield and quality of different field crops in a sustainable agricultural systems is a viable option. Furthermore, biological based alternatives reduce the use of inorgonic synthetic fertilizers and its negative impact on the biosphere.

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