Review Article

Effect of seaweed extracts on crop growth and soil: A Review

ABSTRACT

Seaweed is the common name for countless species of marine plants and algae that grow in the ocean. The seaweed cultivated by bamboo raft, tube mesh and stone method and harvested generally by acid, alkali and water extraction. However, the mostly commercially available in market, which is extracted by processing of bio refinery method. These seaweeds consist of 80-90% moisture. The dry seaweed extracts contains 50% carbohydrates, protein 10-47% with high proportions of essential amino acids, 1-3% lipids and 7-38% minerals. The essential nutrients contain in seaweeds are nitrogen, potassium, phosphorous, calcium, magnesium, sulphur, iron, sodium, zinc, and copper. Seaweed extracts are available in market v*iz*, Sagarika, Kelp, Sea Secret, Sivarika, Solumax, Biovita *etc*. The soil application of liquid seaweed extracts through drip @ 0.5-1 L^{-1} water and foliar @ 2-5 ml L^{-1} of water at various critical growth stages of different crops. The application granules of seaweed were recommended @10-20 kg $acre^{-1}$ during sowing or standing crops. The application of seaweed extracts either through drip or direct application to soil at lower concentrations were positively impact on germination, shoot growth, root growth, nutrient use efficiency, soil properties, soil microbes, biotic stress, abiotic stress and crop yields.

Keywords: Seaweed extract, Foliar spray, Soil microbes, Soil chemical properties, Plant nutrients.

Introduction

"Seaweed extracts are the biostimulant extracted from seaweed (especially brown and red algae) that can promote crop growth, improve crop quality, enhance crop stress resistance and soil health. India's coastline is 7517 km long and has an Exclusive Economic Zone (EEZ) of 2.17 million km^2 (equal to 66% of total mainland area).The Maharashtra also having 720 km seashore. The Central Salt and Marine Chemicals Research Institute explored the seaweed diversity of the Gujarat and Tamil Nadu coasts" (Jha *et al.* 2009). "Around 700 species of marine algae are present and approximately 60 of them being commercially important in both the intertidal and deep-water regions of the Indian coast. Tamil nadu, Gujarat, Maharashtra, Goa, Lakshadweep, Andhra Pradesh, and Karnataka states are major seaweed extracts producers" (Tandel *et al.* 2016). "The seaweed having three major types of species such as Phaeophyceae, Rhodophyta and Chlorophyta. The all commercial seaweed extract products are made from brown seaweeds (*Ascophyllum nodosum, Fucus, Laminaria*, *Sargassum* and *Turbinaria spp. etc.*) and red seaweeds *viz, Kappaphycus alvarezii*, *Hypnea musciformis, Sarconema filiforme, Gracilaria edulis etc". (Hong, Hien, and Son, 2007, Sharma *et al.*, 2012, Ganesan *et al.*2019). "Seaweeds consist of minerals *viz.*, organic components, plant hormones and mixtures of different types of polysaccharides (laminarin, fucoidan and alginates), normally not found in terrestrial plants" (Sivasankari *et al.* 2006, Rioux, Turgeon, and Beaulieu, 2007). The optimum temperature between 25°C and 30°C and salinity should be from 2.7 to 3.5 % for optimum condition for seaweed cultivation (Ganesan, Eswaran, and Reddy, 2017). The seaweed cultivated by bamboo raft method, tube net method and stone method *etc*. (Veeragurunathan *et al.* 2015). "Seaweeds are rich in valuable metabolites, such as natural pigments, proteins, lipids, minerals and cellulose which can be extracted and utilized through biorefinery processing methodologies" (Gajaria *et al.* 2017)

"Seaweed extracts act as chelates which enhances soil mineral element, nutrient-uptake in plant, soil structure and aeration properties of the soil, which ultimately promotes root growth" (Milton 1964). "It also enhanced the adsorption of macronutrients including N, P, K, Ca, Mg, S and micronutrients such as Zn, Mn and Fe" (Crouch, Beckett, and van Staden, 1990, Mancuso *et al*. 2006, Rathore *et al*. 2009, Zodape *et al*. 2011). "Seaweed is an excellent source of bioactive components with reported antimicrobial activity. Several scientific studies in vitro revealed the antimicrobial potential of seaweeds" (Seilaniantz *et al*. 2007).

Table 1. Chemical Composition of Seaweed Extracts

Nutrients	**Contents**
Nitrogen (N)	0.18 %
Phosphorus (P_2O_5)	0.48 %
Potassium (K_2O)	1.89 %
Calcium	0.11 %
Magnesium	0.01 %
Sodium	0.13 %
Iron	256.0 ppm
Zinc	11.87 ppm
Copper	15.62 ppm
Manganese	13.12 ppm

Manimaran, *et al*., 2018.

Effect of seaweed extracts on crop growth attributes

The optimistic effects of seaweed on germination of different agricultural crops and its distinct concentration of seaweed extracts. Munuru *et al*. (2020) perceived that "*Cladophora rupestris* and *Ulva lactuca* species used for seaweed extracts and the optimum concentration of seaweed extracts are surge the rate of germination for cereals and pulses. Advancement in germination percentage, shoot and root length as well as seedling vigour index of rice seeds were noted in lower concentrations of seaweed extracts". "The lower concentrations (5%) of seaweed saps (*Kappaphycus* and *Gracilara* species) exhibited the higher rate of germination of maize seed, however the higher concentration (15%) of the seaweed extracts hinder the germination" (Layek *et al*. 2018, Layek *et al*. 2016). "Application of *Kappaphyccus* or *Gracilara* seaweed sap at 15% concentration notably increased the germination in wheat. But, when the concentration is either below 2.5% or increased upto 20%, remarkably depletion in the germination" (Dilvarnaik *et al*. 2017).

"The higher concentrations of *Kappaphyccus* or *Gracilara* seaweed sap was decline in germination percentage might be cause of consist of high salts concentration at seaweed saps. Salt stress induced inhibition of seed germination, seedling growth and metabolic processes in maize" (Azevedo *et al*. 2004) and wheat (Brini *et al*. 2009). "Germination percentage of different crops were escalated in lower concentrations might be due to IAA and IBA Gibberlins (A & B), micronutrients, vitamins and amino acids. The more concentrations of hormones and minerals had inhibited growth" (Challen and Hemingway, 1966). "Marine algae *Enteromorpha intestinalis* species of seaweed extracts *i.e*. 60% seaweed liquid fertilizer was noticed100% seed germination in soybean (Chetna *et al*. 2015). The seaweed extracts persuade greater seedling growth at a lower concentration in arhar" (Mohan *et al*. 1994). Higher germination percentage and seedling vigour of green gram (Venkataraman and Mohan, 1997) and cowpea (Sivasankari *et al*. 2006) due to application of seaweed. The increase in germination and seedling vigour at low concentrations of seaweed extracts could be due to presence of auxins, gibberellins, phenyl acetic acid (Sivasankari *et al.* 2006) and micro-nutrients (Layek *et al.* 2014).

Effect of seaweed extracts on shoot growth of crops

The soil application of seaweed extract @ 12.5 kg ha^{-1} along with the foliar spraying of seaweed extract of *K. alvareziion* @ 0.5% twice at tillering and panicle initiation stage had significantly higher crop growth parameters of rice like plant height, LAI, DMP and yield parameters viz., number of grains panicle^{-1}, panicle length, number of productive tillers m^{-2} (Deepana *et al.* 2021). Sulakhudin, Hatta, and Suryadi, (2019) reported the application of coastal sediment with the foliar application of seaweed extract (*Eucheuma cottonii*) significantly affect growth parameters at all variety of shallots (*Allium ascalonium* L.). It was an evident that most of the applied coastal sediment and foliar seaweed extract greatly improved leaf length, number of leaf and number of tillers of shallots**.** Mafakheri1 and Asghari (2018) intended that the application of seaweed extract showed maximum shoot lengths, fresh and dry weights, number of pods per plant, chlorophyll “a”, chlorophyll “b”, total chlorophyll, and carotenoids of *Trigonella foenum graecum* L. Hidangmayum *et al.* (2017) observed “the effect of different concentrations of commercial seaweed liquid extract of *Ascophyllum nodosum* as a plant biostimulant on growth, yield and biochemical constituents of onion (*Allium cepa* L.). They concluded that seaweed liquid extracts play an important role for increasing plant height, leaf number, bulb diameter, protein content, sulphur content and chlorophyll and carotenoid contents of onion. Plant which received 0.55% concentration found superior to all treatments while the increased in concentration shows decreasing trends”. The application of seaweed extract also increases higher leaf length in onion on sandy soil (Shafeek, Helmy, and Omar, 2015). The *Ascophyllum nodosum* extract and its organic subfractions increment in more functional nodules might be the legume–rhizobia signaling processes as well as enhancement in growth of alfalfa plants (Khan *et al*. 2013).

Sutharsan, Nishanthi, and Srikrishnah, (2014) studied the effects of foliar application of seaweed (*Sargassum crassifolium*) liquid extract (10%, 20%, 50% and 100%) on the leaf number, leaf area, plant height, shoot dry weight, root dry weight, number of flower and number of fruits *etc.* in the *Lycopersicon esculentum* and result showed that increased growth parameters as compare to other treatments. *Kappaphyccus* extract @ 15% three foliar spray with recommended dose of fertilizers (RDF) registered higher yield attributes of rice crop such as number of panicles m^{-2} (507.60), filled grains panicle^{-1} (143.83), panicle length (28.97 cm) and 1000 grain weight (21.23 g) and followed by treatment *Gracilaria* sap @ 15% three foliar spray with RDF. The highest number of panicles hill^{-1} and number of effective grains panicle^{-1} of rice was found in 15% *Kappaphyccus* extract and it was statistically at par with 10 % and 5% *Kappaphyccus* extract sap concentrations (Layek *et al.* 2018). The application of brown algal seaweed extracts boost growth of the crop and elevating number of functional nodules might be due to content of cytokinins (Saravanan *et al*. 2003). Augmentation of plant height, number of pods plant^{-1}, number of grains plant^{-1}, number of branches plant^{-1} of soybean was noted in treatment of 15% seaweed extract from *Kappaphycus alvarezii* (Rathore *et al.* 2009).

Effect of seaweed extracts on root growth of crops

The soil application 12.5 and 25 kg ha^{-1} with foliar spraying of seaweed extracts liquid 0.5 % (v/v) at tillering + panicle initiation stage have significant effect on the root length of rice crop (Deepana *et al.* 2021). “The effect of seaweed extracts on different cultivars of onion and they indicated that seaweed extracts application led to an increase in root length which can be ascribed to alginate oligosaccharide-induced expression of an auxin-related gene leading to higher auxin concentrations, thus promoting root formation and elongation” (Abbas *et al*. 2020). Mostly Marine algae loaded with auxins and its different compounds

(Crouch and Staden 1992). An *Ascophyllum nodosum* extract content 50 mg IAA (indole acetic acid) per gram of dry extract (Kingman and Moore, 1982). *Ecklonia maxima* species extract also content of auxins which is noticeable change was found in mung bean root (Crouch and Staden, 1992). The seaweed extract also detected the indole compounds and IAA in Gas chromatography /mass spectroscopy method (Crouch *et al.* 1992).

Seaweed products are inciting the root growth and development activity (Metting *et al*. 1990, Jeannin, Lescure, and Morot-Gaudry, 1991). The root-growth invigorating effect was more notable when extracts were applied at an early growth stage in maize, and the response was similar to as that of auxin, an important root growth-promoting hormone (Jeannin, Lescure, and Morot-Gaudry, 1991). Seaweed extracts applications minimises transplanting shock in seedlings of marigold, cabbage (Aldworth and Van Staden 1987), and tomato (Crouch and Staden 1992) by increasing root size and vigour (Crouch and Van Staden 1992). Similarly, wheat plants treated with seaweed extracts Kelpak observed an increase in root:shoot dry mass ratio.The seaweed had a significant effect on root development (Nelson and Staden 1986). Seaweed extracts were applied either roots or as a foliar spray to the plant excited to the root growth activity as reported by Biddington and Dearman 1983, Finnie and Staden 1985. The concentration of kelp extract is a crucial factor in its effectiveness as reported by Finnie and Van Staden (1985) in tomato plants, the excessive concentrations (1:100 seaweed extract:water) inhibited root growth, however lesser concentration (1:600) stimulates the root activity. Biostimulants of seaweed extracts having capacity of root development by improving lateral root formation (Vernieri *et al.* 2005) and increasing total mass of the root system (Thompson 2004, Slavik 2005, Mancuso *et al*. 2006). The seaweed extracts consist of endogenous auxins and root growth promoting substances were responsible for enhancement of root system (Crouch *et al.* 1992).

Effect of seaweed extracts on crop yield

Banjare *et al.* (2022) recorded significant effect of Sagarika seaweed granule and liquid extracts on rice crop in *Vertisols.* The highest yield (62.9 q ha^{-1}) of rice was noted in the treatments of 100% RDF + seaweed granules @ 25 kg ha^{-1} at 21 DAT + seaweed liquid @ 0.25% at 42 DAT. The addition of seaweed extracts with 75% RDF increased grain yield by 4.6, 7.9, 11.0, and 12.1% (highest) over the application of 75% RDF alone (52.58 q ha^{-1}). The seaweed extract fertilizer saving of 20% fertilizer with increase the rice yield.The treatment of chemical fertilizer, chemical fertilizer with 5% seaweed extract, and low chemical fertilizer with 5% seaweed extract had increased yield by 58.42%, 62.51%, and 62.06%, respectively over the control (Chen *et al.* 2022). Hassan *et al.* (2021) reported that the true algae max (*Ulva lactuca, Jania rubens,* and *Pterocladia capillacea*) increased cucumber yield due to improving its chemical and physical traits related to immunity, productivity, and stress defence of cucumber. Chen *et al.* (2021) noticed that spraying seaweed extract once at seedling, early elongation, and early mature stages increased the cane yield by 9.23, 9.01, and 3.33%, respectively.

Deepana *et al*. (2021) observed that the soil application of seaweed extract @ 12.5 kg ha^{-1} along with the foliar spraying of seaweed extract liquid @0.5% twice at tillering and panicle initiation stage had significantly increased yield by 18 -20%. The 18.0 percent increase in grain yield of rice was noted in treatment @15% *Kappaphyccus* or *Gracilaria* extracts over the control (Layek *et al*. 2018). Application of either 10% concentration of *Kappaphyccus* or *Gracilaria* extracts of foliar spray along with 100% RDF was beneficial option to attain high yield and grain quality of rice in North Eastern region of India (Patel *et al*. 2015 and Singh *et al*. 2015). "Application of biochar (2 and 5 %) with the seaweed extracts (1 and 2 g L^{-1}) gave positively enhanced plant growth, development, yield and the mineral composition of wheat plants cv. *Sakha* 93 cultivated in sandy soil. The seaweed components providing an excellent source of bioactive compounds such as macro- and micronutrients, essential fatty acids, amino acids, vitamins, cytokinins, auxins like growth promoting substances affecting cellular metabolism in treated plants leading to enhance growth and productivity" (Badry and Salim 2016).

The *Kappaphycus alvarezii* and *Gracilaria edulis* extract concentrations 7.5% and 5.0% foliar spray had improve 19.74% and 13.16% of grain yield of wheat, respectively (Shah *et al*. 2013). Similar results have been also noted in wheat with the application of *Kappaphycus alvarezii* seaweed extract (Zodape *et al*. 2009). The treatments RDF + *Kappaphycus alvarezii* @ 10 % and RDF + *Gracilaria edulis* @10% seaweed extracts were produced significantly superior tuber yield 32.88 t ha^{-1} and 31.30 t ha^{-1}, respectively over the control. Seaweed extracts foliar sprays were increased marketable yield of tuber and decline in non-marketable tuber yields of potato (Prajapati *et al*. 2016). The increase in 47.52 and 42.52 grain yield of black gram due to application of @10% *Kappaphyccus Alvarezii* and *Gracilaria edulis* extracts, respectively (Jadhao *et al*. 2015). The foliar sprays of seaweed extracts maximise upto 25% yield of bean (Temple and Bomke, 1989).

The application of 15% seaweed extracts was noticed higher straw yield of green gram (Pramanick, Brahmachari, and Ghosh, 2013). The application of seaweed extracts was significantly higher oil content, oil yield, K, Na and crude protein of sunflower seed. Application of @ 0.6 % *Gracilaria dendroides* and *Ulva lactuca spp* of seaweed extracts was noted higher oil content 34.05 and 30.55 percent in sunflower, respectively (Hannan and Salem, 2011). The foliar spray of seaweed extract at 30 and 60 days of interval after planting of potato resulted higher tuber yield and quality parameters *viz,* nitrogen, total soluble solids and protein contents in potato tubers (Haider *et al*. 2012). The application of seaweed extracts founded beneficial effect on growth, yield and quality of potato tubers (Sarhan, 2011). The foliar applications of 15% and 12.5% seaweed extracts were noticed 57% and 46% increase in grain yield of soybean over to control (Rathore *et al*. 2009). Applications of @15% *Kappaphycus* extracts + RDF and @15% *Gracilaria* extracts + RDF had been recorded 38.97 and 33.58% higher grain yield of green gram, respectively as compared to the without application of seaweed extracts. The extracts of *Kappaphycus* and *Gracilaria* seaweed consist of micronutrients and growth harmone (Zodape *et al*. 2011) which is responsible for boosting the crop yield and enhancing quality of green gram in foliar application treatments. Application of seaweed extract creates early growth and improved the yield contributing characters of legume crops as well as increase in 12-25% higher yield as compared to control (Sethi and Adhikary, 2008). Significant increase in yield of different crops due to foliar application of seaweed extracts has been reported by Arthur, Stirk, and Staden, 2003.

Effect of seaweed extracts on soil properties

Effect of seaweed extracts on soil microbial activity

The application seaweed extract to tomato plantation significantly increased soil bacteria, this might be due to decompose the cellular matter and supply the soil carbon to microorganisms (Hussain *et al*. 2021). The increased number of 14 bacterial families in soils treated with seaweed extract (Khan *et al*. 2012, 2013, Shukla *et al*. 2019). The application of seaweed extracts along with organic matter shown increase fungal families in soils (Renaut *et al*. 2019).

Application of seaweeds and seaweed extracts activated growth of beneficial soil microbes and synthesis of soil aggregating agents which change in soil quality for sustainable growth of crops. Kuwada *et al*. (2006) reported that organic fractions (25% MeOH eluates) of red and green algae found that the substantially increase hyphal growth of arbuscular mycorrhiza(AM) fungi in vitro. The results also elucidated that 25% MeOH eluates of red and green algal extracts applied to roots of papaya (*Carica papaya Linn*.) and passion fruit (*Passiflora edulis Sims*.) enhanced mycorrhizal count as compare to control treatment. Kuwada *et al*. (2006) inferred that both red and green algae present arbuscular mycorrhiza enhancing substances which play a role in mycorrhizal growth in higher plants. Marine brown seaweed [*Laminaria japonica Areschoug and Undaria pinnatifida (Harvey) Suringar*] extracts may be used as an enhancing the growth of AM fungus (Kuwada *et al.* 2006). Ishii *et al.* (2000) noted that the higher in stimulated hyphal and elongation of arbuscular mycorrhizal (AM) fungi activity might be due to alginate oligosaccharides extracted from brown algae. Methanol extracts from brown algae augmented growth of arbuscular mycorrhiza fungi on trifoliate orange, *Poncirus trifoliate* (Linn.) Raf., seedlings (Kuwada *et al.* 1999). Indigenous AM fungi intended a 27% growth in root colony and spore number was increased 21% over the control when liquid fertilizer containing tangle (L. *japonica*) extracts was given in a sprinkler system used in citrus orchard (Kuwada *et al.* 2000).

Effect of seaweed extracts on soil chemical properties:

Application of seaweed extract before sowing or even standing crop improves the soil chemical properties. This seaweed extract as manure provide essential nutrients to enhance crop growth (Munuru *et al.* 2020). Application of coastal sediment with foliar application of seaweed extract improved chemical properties *i.e.* pH and the availability of K, Ca, Mg and Na of peat soil (Sulakhudin, Hatta, and Suryadi, 2019). During the decomposition of seaweed extract (*Sargassum horneri*) releases of nitrate, ammonium, total nitrogen, and phosphorus. Also chelate with major cations of Na^+, Ca^{2+}, Mg^{2+}, and K^+ to form aggregate with richer nutrients, improve the soil structure and ultimately boost the activity of soil microorganism. Therefore, seaweed extract supplement can potentially be a strategy of enhancing the level of N, P, and K contents in soil (Chen *et al.* 2022). Deepana *et al.* (2021) reported that the soil application of seaweed extract @ 25 kg ha^{-1} was noticed remarkable improvement in available nutrient status like N, P, K, Ca, Mg, S and micronutrients in soil.

Seaweed extracts (brown algae *Durvillaea potatorum* and *Ascophyllum nodosum*) increases available nitrogen content in soil (Hussain *et al.* 2021). Seaweed as a partial source of nitrogen (40–55%) used as a organic fertilizer treatment for comparison in sweet corn. Soil electrical conductivity, potassium (K^+), sulphate (SO_4^{2-}), and active carbon (C) increased with seaweed addition relative to the organic fertilizer, where as potentially mineralizable N and pH decreased, with effects varying over time (Possinger and Amador 2016).

Effect of seaweed extracts on nutrient uptake by crops

The effect of Sagarika seaweed granule and liquid extracts on rice crop in *Vertisols.* Application of 100% RDF along with the soil and foliar application of seaweed extract of granule (solid) and liquid formulations had maximum nutrient uptake of rice due to increasing nutrient use efficiency (Banjare *et al.* 2022). Hellequin *et al.* (2020) resulted that the biostimulant prepared from seaweed extracts induced changes in the soil stoichiometry with a greater content of NO_3^- and a lower content of PO_4^{3-} without impacting the soil content of NH_4^+. Spraying seaweed extracts to sugarcane crop once at seedling, early elongation, and early mature stages increased N, P, or K utilization efficiency as compared to without spraying seaweed (Chen *et al.* 2021). Senthuran *et al.* (2018) noticed that the remarkably higher uptake of P and K in leaves of *amaranthus polygamous* noted in the foliar application of 10% seaweed extarcts (*kappaphycus alvarezii*) combined with 50% chemical fertilizer treatments resulted higher values compared to that in chemical fertilizer alone in sodic soil. Seaweed act as biostimulant had a favorable effect on N uptake in shoots, roots and whole plants of oilseed rape at the fruit development stage (Siwik-Ziomek and Szczepanek 2019).

Badry and Salim (2016) observed that the impact of application of biochar (2 and 5 %) with the seaweed extracts (1 and 2 g L^{-1}) having enhancing the use efficiency of nutrients in sandy soil. Pramanick, Brahmachari, and Ghosh, (2014) reported that the highest N, P and K uptake by rice grain and straw were recorded in the 15% *Kappaphycus sap.* + RDF and 15% *Gracilaria* sap + RDF over the RDF and control treatment. Increased root and shoot growth in rapeseed treated with extract were associated with enhanced uptake and accumulation of nitrogen and sulphur in rapeseed (Jannin *et al.*, 2013). In addition, chemical components of brown seaweed extract are known to induce growth and root colonization of beneficial soil fungi (Kuwada *et al.*, 2000, 2006). Alginic acid, a major component of brown seaweed extracts, promoted hyphal growth and elongation of arbuscular myocorrhizal fungi (Ishii *et al.*, 2000), such proliferation of mycorrhizal fungi lead to an improvement in phosphorus nutrition of plants. Foliar spray of seaweed extract products *Ascophyllum nodosum* extract improved the Cu uptake in grapevine, probably by increased permeability of the cell membrane. Application of a commercial extract of *Ecklonia maxima* on lettuce grown under optimal conditions improved yield and Ca, K and Mg content in the leaves (Crouch, Beckett, and Van Staden, 1990).

Effect of seaweed extracts on abiotic and biotic stresses in crops

“Application of seaweed extract sprays of *Ascophyllum nodosum* (5 and 7 $mL{\cdot}L^{-1}$ with 6 day intervals) on *Paspalum vaginatum* Salam’ during prolonged irrigation intervals (2 and 6 day) and saline growing conditions (1 and 49.7 dS m^{-1}) for 6 weeks. The results stated that the seaweed extracts increased turf quality, leaf photochemical efficiency, root length and dry weight, total non-structural carbohydrates, K, Ca, and proline in treated plants during prolonged irrigation intervals as well as saline shock conditions” (Elansary *et al.* 2017). “The seaweed extract could enhance the photosynthetic rates by reducing stomatal closure and increasing gas exchange, leading to improved growth during drought conditions” (Elansary, Skalicka-Woźniakc, and King, 2016). “The seaweed extract of *Ascophyllum nodosum* significantly delayed wilting, better water use efficiency, increased leaf water content and improved the recovery of drought wilted plants, as compared to controls” (Little and Neily, 2010, Neily *et al*., 2008).

“The seaweed extract consist of bioactive element which enhance the performance of plants under abiotic stresses. Foliar applications of extracts have been shown to improve plant tolerance to freezing temperature stress” (Mancuso *et al*., 2006). Application of an *Ascophyllum nodosum* extract formulation applied to grapes enhanced freezing tolerance might be due to lowering of osmotic potential in leaves. The average osmotic potential of seaweed extract treated grape plants was −1.57 MPa correlated with −1.51 MPa in the without treated plants of grape later 9 days of seaweed extract application to grape plants (Wilson, 2001). Aberrant changes in rainfall, higher concentration of salts in soil, and temperature extremes are responsible for decline the yield of main crops (Wang, Pote, and Hua, 2003) and adversely effect on agricultural sector in a global. For example, soluble salt concentrations and limited rains are the mainly responsible for abiotic stresses in many areas of the world, with an estimated 50% of all cultivated lands are degrading due to salinization by 2050 (Flowers and Yeo, 1995). The abiotic stresses had also causes secondary effects like oxidative stress, leading to an accumulation of reactive oxygen species (ROS) such as the superoxide anion (O_2^-) and hydrogen peroxide (Mittler, 2002). These are known to damage DNA, lipids, carbohydrates, and proteins and also cause aberrant cell signaling (Arora, Sairam, and Srivastava, 2002). *Ascophyllum* extracts *i.e.* Seasol (0.8%) sprayed on grape vines noted that the reduction in leaf osmotic potential, enhanced freezing tolerance in grape vine. The seaweed extract contain cytokinin is role in heat tolerance mechanism in creeping bent grass (Ervin, Zhang, and Fike, 2004, Zhang and Ervin 2008).

The seaweeds *viz. Sargassum polyphyllum, Turbinaria ornata, Gelidiopsis sp., Padina tetrastomatica* and *Gracilaria corticata* as a stimulant to boost the growth of *Vigna radiata* (Mung) as well as its antagonistic activity against several fungal pathogens such as *Rhizoctonia solani*, *Alternaria solani* and *Sarocladium oryzae*) (Sarkar *et al.* 2018). Diseases of broccoli caused by *Albugo candida* and *Sclerotinia* were effective control with joint application of seaweed extract from *Ascophyllum nodosum* and *Durvillaea potatorum*

(Mattner *et al.* 2014). This combination was also found effective against club root disease caused by *Plasmodiophora brassicae* (Wite *et al.* 2015)**.** Seaweeds are a good source of antioxidant polyphenols with bactericidal properties (Zhang *et al.* 2006). The increase in superoxide dismutase (SOD) activity might be due to *Ascophyllum nodosum* and humic acid application in bentgrass (*Agrostis stolonifera*), which remarkably reduced dollar spot disease caused by *Sclerotinia homoeocarpa*. Loon *et al.* (2006) reported that the *ulva* extract extort the expression of the PR-10 gene required for active defence against diseases of pathogen attack. "The cDNA array revealed that the seaweed extract caused upregulation of 152 genes, mostly plant defence genes such as those involved in phytoalexin, PR proteins, cell wall proteins, and oxylipin pathways" (Cluzet *et al.* 2004). "Soil application of liquid seaweed extracts to cabbage stimulated the growth and activity of microbes that were antagonistic to *Pythium ultimum*, a serious fungal pathogen that causes damping-off disease of seedlings" (Dixon and Walsh 2002). "Seaweed extracts was induced plant defence mechanism counter to pest and diseases of plants" (Allen *et al.* 2001). The seaweed products enhancing plant defence mechanism for sustainable plant health as well as rhizosphere microbial community in soil.

Conclusion

Seaweed is the best biostimulant, good source of essential nutrients, excellent eco-friendly organic manure and alternative source for inorganic chemical fertilizer for sustaining the crop yield. Mostly Seaweed spp. *Ascophyllum, Fucus, Laminaria, Sargassum, Turbinaria, Kappaphycus, Sarconema, Gracilaria etc* are used for preparation of seeweed extracts which helps in enhancing cereal, pulses, vegetables, fruit crop growth, yield and quality. The seaweed extracts stimulating soil microbial activity as well as improved the soil fertility, quality, increasing the nutrient use efficiency and mitigating drought, salinity and chilling injury. Howerer, *Ulva, Durvillaea, Ascophyllum, Turbinaria, Gelidopsis Spp. etc.* creates disease resistance in crop.

References

Arora, A., Sairam, R. K., and Srivastava, G. C. 2002. Oxidative stress and antioxidative systems in plants. Current Science, 82(10): 1227–1238.

Arthur, G. D., Stirk, W. A., and van Staden, J. 2003. Effect of a seaweed concentrate on the growth and yield of three varieties of Capsicum annuum. *South African Journal of Botany,* 69: 207–211.

Azevedo Neto, A. D., Prisco, J. T., Eneas, F. J., Lacerda, C. F., Silva, J. V., Costa, P. H. A., and Gomes, F. E. 2004. Effects of salt stress on plant growth, stomatal response and solute accumulation of different maize genotype. *Brazilian Journal Plant Physiology,* 16(1): 31-38.

Banjare, L., Banwasi, R., Jataw, G. K., and Shrivastav, L. K. 2022. Effect of seaweed extract on yield and nutrient uptake of rice in a vertisol. *The Pharma Innovation Journal,* 11(3): 2193-2198

Biddington, N. L., and Dearman, A. S. 1983. The involvement of the root apex and cytokinins in the control of lateral root emergence in lettuce seedlings. *Plant Growth Regulation,* 1: 183–193.

Brini, F., Amara, I., Feki, K., Hanin, M., Khoudi, H., and Masmoudi, K. 2009. Physiological and molecular analyses of seedlings of two Tunisian durum wheat (*Triticum turgidum* L. sub sp. Durum [Desf.]) varieties showing contrasting tolerance to salt stress. *Acta Physiologiae Plantarum,* 31(1): 145 - 154.

Challen, S.B., and Hemingway, J. C. 1966. Growth of higher plants in response of feeding with seaweed extracts. In Proceedings, 5th International Seaweed Symposium, 25-28

August 1966, Halifax Publisher, Oxford.

Chetna, M., Rai, S., Sase, N., Krish, S., and Mangalam, A. J. 2015. Enteromorpha intestinalis derived seaweed liquid fertilizers as prospective biostimulant for *Glycine max*. *Brazilian Archives of Biology and Technology,* 58(6): 813-820.

Chen, C. L., Song, W. L., Sun, L., Qin, S., Ren, C. G., Yang, J. C., Feng, D. W., Liu, N., Yan, J., Cui, B. B., Zhong, Z. H., Li, Q. Q., Liu, Z. D., and Liu, Z. Y. 2022. Effect of seaweed extract supplement on rice rhizosphere bacterial community in tillering and heading stages. *Agronomy*, 12(2): 342.

Chen, D., Zhou, W., Yang, J., Ao, J., Huang, Y., Shen, D., Jiang, Y., Huang, Z., and Shen, H. 2021. Effects of seaweed extracts on the growth, physiological activity, cane yield and sucrose content of sugarcane in China. *Frontiers in Plant Science*, 12: 659130.

Cluzet, S., Torregrosa, C., Jacquet, C., Lafitte, C., Fournier, J., Mercier, L., Salamagne, S., Briand, X., Esquerré-Tugayé, M.T., and Dumas, B. 2004. Gene expression profiling and protection of Medicago truncatula against a fungal infection in response to an elicitor from the green alga Ulva spp. *Plant Cell Environment,* 27: 917–928.

Crouch, I. J., Beckett, R. P., and van Staden, J. 1990. Effect of seaweed concentrate on the growth and mineral nutrition of nutrient stressed lettuce. *Journal of Applied Phycology,* 2: 269–272.

Crouch, I. J. and van Staden, J. 1992. Effect of seaweed concentrate on the establishment and yield of greenhouse tomato plants. *Journal of Applied Phycology,* 4: 291–29.

Dilavarnaik, S., Basavaraja, P. K., Yogendra, N. D., and Ghosh, A. 2017. Influence of seaweed saps on germination, growth and yield of hybrid maize under Cauvery Command of Karnataka, India. *International Journal of Current Microbiology and Applied Sciences,* 6(9): 1047-1056.

Dixon, G. R. and Walsh, U. F. 2002. Suppressing Pythium ultimum induced damping-off in cabbage seedlings by biostimulation with proprietary liquid seaweed extracts managing soil-borne pathogens: a sound rhizosphere to improve productivity in intensive horticultural systems. Proceedings of the XXVIth International Horticultural Congress, Toronto, Canada, 11–17 August 2002, pp 11–17.

Deepana, P., Bama, K. S., Santhy, P., and Devi, T. S. 2021. 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*, 13(3): 1111-1120.

Elansary, H. O., Yessoufou, K., Abdel-Hamid, A. M., El-Esawi, M. A., Ali, H. M., and Elshikh, M. S. 2017. Seaweed extracts enhance Salam turfgrass performance during prolonged irrigation intervals and saline shock. *Frontiers in Plant Science*, 8: 830.

Elansary, H. O., Skalicka-Woźniakc, K., and King, I. W. 2016. Enhancing stress growth traits as well as phytochemical and antioxidant contents of Spiraea and Pittosporum under seaweed extract treatments. *Plant Physiology Biochemistry*, 105: 310–320.

Ervin, E. H., Zhang, X., and Fike, J. 2004. Alleviating ultraviolet radiation damage on Poa pratensis: II. Hormone and hormone containing substance treatments. *American Society for Horticultural Science,* 39: 1471–1474.

Finnie, J. F., and van Staden, J. 1985. Effect of seaweed concentrate and applied hormones on in vitro cultured tomato roots. *Journal of Plant Physiology*, 120: 215–222.

Flowers, T. J., and Yeo, A. R. 1995. Breeding for salinity resistance in crop plants—where next? *Australian Journal of Plant Physiology,* 22(6): 875–884.

Gajaria, T. K., Suthar, P., Baghel, R. S., Balar, N. B., Sharnagat, P., Mantri V. A., and Reddy, C. R. K. 2017. Integration of protein extraction with a stream of byproducts from marine macroalgae: a model forms the basis for marine bioeconomy. *Bioresource. Technology*. 243: 867–873.

Ganesan, M., Eswaran, K., and Reddy, C. R. K. 2017. Farming of agarophytes in India – a long time sustainability for the industry and preserving wild stocks. *Journal of Applied Phycology*, 29: 2239–2248

Ganesan, M., Trivedi, N., Gupta, V., Madhav, S. V., Reddy, C. R., and Levine, I. A. 2019. Seaweed resources in India–current status of diversity and cultivation: prospects and challenges. *Botanica Marina*, 62(5): 463-482.

Haider, W., Chaudhary, M. A., Muhammad, A. P., Habat, U. A., Abdul, M., Syed, A. R., and Irfan, A. 2012. Impact of foliar application of seaweed extract on growth, yield and quality of potato (*Solanum tuberosum* L.). *Soil and Environment,* 31(2): 157-162.

Hassan, S. M., Ashour, M., Sakai, N., Zhang, L., Hassanien, H. A., Gaber, A., and Ammar, G. 2021. Impact of seaweed liquid extract biostimulant on growth, yield, and chemical composition of cucumber (*Cucumis sativus*). *Agriculture,* 11(4): 320.

Osman, H. E., and Salem, O. M. A. 2011. Effect of seaweed extracts as foliar spray of sunflower yield and oil content. *Egyptian Journal of Phycology*, 12: 57-69.

Hellequin, E., Monard, C., Chorin, M., Le Bris, N., Daburon, V., Klarzynski, O., and Binet, F. 2020. Responses of active soil microorganisms facing to a soil biostimulant input compared to plant legacy effects. *Scientific Reports*, 10(1): 13727.

Hidangmayum, A., and Sharma, R. 2017. Effect of different concentrations of commercial seaweed liquid extract of Ascophyllum nodosum as a plant bio stimulant on growth, yield and biochemical constituents of onion (*Allium cepa* L.). *Journal of Pharmacognosy and Phytochemistry*, 6(4): 658-663.

Hong, D. D., Hien, H. M. and Son, P. N. 2007. Seaweeds from Vietnam used for functional food, medicine and biofertilizer. *Journal of Applied Phycology*, 19: 817–826.

Hussain, I., Ahmed, M., Khan, S., Khalid, A., Ali, S., Hussain, I., and Sajid, M. 2017. Screening of different exotic lines of tomato (*Lycopersicon esculentum* L.) under the agro-climatic condition of Haripur. *Pure and Applied Biology*, 6: 1251–1259.

Hussain, H. I., Kasinadhuni, N., and Arioli, T. 2021. The effect of seaweed extract on tomato plant growth, productivity and soil. *Journal of Applied Phycology*, 33(2): 1305-1314.

Ishii T, Aikawa J, Kirino S, Kitabayashi H, Matsumoto I, Kadoya K. 2000. Effects of alginate oligosaccharide and polyamines on hyphal growth of vesicular-arbuscular mycorrhizal fungi and their infectivity of citrus roots. In: Proceedings of the 9th International Society of Citriculture Congress, Orlando, FL, 3–7 December 2000, pp 1030–1032.

Jadhao, G.R., Chaudhary, D. R., Khadse, V. A., and Zodape, S.T. 2015. Utilization of seaweeds in enhancing productivity and quality of black gram [*Vigna mungo* (L.) Hepper] for sustainable agriculture. *Indian Journal of Natural Products and Resources*, 6(1): 16-22.

Jannin, L., Arkoun, M., Etienne, P., Laîné, P., Goux, D., Garnica, M., Fuentes, M., Francisco, S. S., Baigorri, R., and Cruz, F. 2013. Brassica napus growth is promoted by *Ascophyllum nodosum* (L.) Le Jol. seaweed extract: microarray analysis and physiological characterization of N, C, and S metabolisms. *Journal of Plant Growth Regulation*, 32: 31–52.

Jeannin, I., Lescure J. C., and Morot-Gaudry, J. F. 1991. The effects of aqueous seaweed sprays on the growth of maize. *Botanica Marina,* 34: 469–473.

Jha, B., Reddy, C. R. K., Thakur, M. C., and Rao, M. U. 2009. *Seaweeds of India: the diversity and distribution of seaweeds of Gujarat coast* (Vol. 3). Springer Science and Business Media.

Kingman, A. R., and Moore, J. 1982. Isolation, purification and quantification of several growth regulating substances in Ascophyllum nodosum (Phaeophyta). *Botanica Marina,* 25: 149–153

Khan, W., Zhai, R., Souleimanov, A., Critchley, A., Smith, D., and Prithiviraj, B. 2012.

Commercial extract of Ascophyllum nodosum improves root colonization of Alfalfa by its bacterial symbiont Sinorhizobium meliloti. *Communications in Soil Science and Plant Analysis,* 43: 2425–2436.

Khan, W., Palanisamy, R., Critchley, A., Smith, D., Papadopoulos, Y., and Prithiviraj, B. 2013. Ascophyllum nodosum extract and its organic fractions stimulate Rhizobium root nodulation and growth of *Medicago sativa* (Alfalfa). *Communications in Soil Science and Plant Analysis,* 44: 900– 908.

Kobayashi, F., Maeta, E., Terashima, A., Kawaura, K., Ogihara, Y., and Takumi, S. 2008. Development of abiotic stress tolerance via bZIP-type transcription factor LIP19 in common wheat. *Journal of Experimental Botany*, 59(4): 891–905.

Kuwada, K., Ishii, T., Matsushita, I., Matsumoto, I., and Kadoya, K. 1999. Effect of seaweed extracts on hyphal growth of vesicular– arbuscular mycorrhizal fungi and their infectivity on trifoliate orange roots. *Journal of Japanese Society for Horticultural Science*, 68(2): 321–326.

Kuwada, K., Utamura, M., Matsushita, I., and Ishii, T. 2000. Effect of tangle stock ground extracts on in vitro hyphal growth of vesicular arbuscular mycorrhizal fungi and their in vivo infections of citrus roots. In: Proceedings of the 9th International Society of Citriculture Congress, Orlando, FL, 3–7 December 2000, pp 1034–1037.

Kuwada, K., Wamocho, L. S., Utamura, M., Matsushita, I., and Ishii, T. 2006. Effect of red and green algal extracts on hyphal growth of arbuscular fungi, and on mycorrhizal development and growth of papaya and passionfruit. *Agronomy Journal,* 98(5): 1340–1344.

Layek, J., Das, A., Ramkushna, G. I., Ghosh, A., Panwar, A. S., Krishnappa, R., and Ngachan, N. V. 2016. Effect of seaweed sap on germination, growth and productivity of maize (Zea mays) in North Eastern Himalayas. *Indian Journal of Agronomy*, 61 (3): 354-359.

Layek, J., Das, A., Ramkrushna, G. I., Sarkar. D., Ghosh. A., Zodape, S.T., Lal, R., Yadav, G. S., Panwar, A. S., Ngachan. S., and Meena, R. S. 2018. Seaweed extract as organic bio-stimulant improves productivity and quality of rice in eastern Himalayas. *Journal of Applied Phycology*, 30: 547-558.

Little, H., and Neily, W. 2010. Commercial extracts of the brown seaweed Ascophyllum nodosum improve plant water use and drought stress resistance in the greenhouse and field. Oral presentation. Western Plant Growth Regulator Society Annual Meeting. Davis, California.

Lu, T., Ke, M., Lavoie, M., Xiaoji, F., Zhenyan, Z., Zhengwei, F., Liwei, S., Gillings, M., Penuelas, P., Haifeng, Q., and Yong-Guan, Z. 2018. Rhizosphere microorganisms can influence the timing of plant flowering. *Microbiome,* 6: 231.

Mafakheri, S., and Asghari, B. 2018. Effect of seaweed extract, humic acid and chemical fertilizers on morphological, physiological and biochemical characteristics of Trigonella *Foenum-Graecum* L. *Journal of Agricultural Science and Technology,* 20(7): 1505-1516.

Mancuso, S., Azzarello, E., Mugnai, S. and Briand, X. 2006. Marine bioactive substances (IPA extract) improve foliar ion uptake and water stress tolerance in potted Vitis vinifera plants. *Advances in Horticultural Science,* 20(2): 156–161.

Manimaran, P., Lakshmi, J., and Rajasekar, P. 2018. Influence of foliar application of seaweed extract and plant growth regulators on growth and physiological attributes of Jasminum sambac. *Environment and Ecology*, 36(1A): 262-264.

Mantri, V.A., Eswaran, K., Shanmugam, M., Ganesan, M., Veeragurunathan, V,, Tiruppathi, S., Reddy, C. R. K., and Seth, A. 2017. An appraisal of commercial farming of *Kappaphycus alvarezii* in India: Success in diversification of livelihood and prospects. *Journal of Applied Phycology*, 29: 335–357.

Mattner, S.W., Wite, D., Riches, D. A., Porter, I. J., and Arioli, T. 2013. The effect of kelp extract on seedling establishment of broccoli on contrasting soil types in southern Victoria, Australia. *Biological Agriculture and Horticulture*, 29(4): 258–270.

Metting, B., Zimmerman, W. J., Crouch, I. J., and Van Staden, J. 1990. Agronomic uses of seaweed and microalgae. In: Akatsuka I (ed) Introduction to applied phycology. SPB Academic Publishing, *The Hague*, Netherlands, 269–627pp.

Mohan, V.R., Venkataraman, K.V., Murugeswari, R., and Muthuswami, S. 1994, Effect of crude and commercial seaweed extract on seed germination and seedling growth in *Cajanus cajan* L. *Phyko*, 33: 47–51.

Milton, R. F. 1964. Liquid seaweed as a fertilizer. *Proceeding of International Seaweed Symposim*, 4(1964): 428–431.

Mittler, R. 2002. Oxidative stress, antioxidants and stress tolerance. *Trends in Plant Science*, 7: 405–410.

Nelson, W.R., and Van Staden, J. 1986. Effect of seaweed concentrate on the growth of wheat. *South African Journal of Science*, 82: 199–200.

Neily, W., Shishkov, L., Tse, T. and Titus, D. 2008. Acadian LSC helps reduce salinity stress in Pepper seedlings- cv. California Wonder. *PGRSA Newsletter*, 1: 14.

Patel, V.P., Deshmukh, S., Patel, A., and Ghosh, A. 2015. Increasing productivity of paddy (*Oryza sativa* L.) through use of seaweed sap. *Trends in Biosciences*, 8(1): 201–205.

Pramanick, B., Brahmachari, K., and Ghosh, A. 2013. Effect of seaweed saps on growth and yield improvement of green gram. *African Journal of Agricultural Research*, 8(13): 1180–1186.

Pramanick, B., Brahmachari, K., and Ghosh, A. 2014. Efficacy of Kappaphycus and Gracilaria sap on growth and yield improvement of sesame in new Alluvial soil. *Journal of Crop and Weed*, 10(1): 77-81.

Prajapati, A., Patel, C. K., Singh, N., Jain, S. K., Chongtham, S. K., Maheshwari, M. N., Patel, C. R., and Patel, R. N. 2016. Evaluation of seaweed extract on growth and yield of potato. *Environment and Ecology*., 34 (2): 605-608.

Possinger, A. R., and Amador, J. A. 2016. Preliminary evaluation of seaweed application effects on soil quality and yield of sweet corn (*Zea mays L*.). *Communications in Soil Science and Plant Analysis*, 47 (1): 121-135.

Rathore, S. S., Chaudhary, D. R., Boricha, G. N., Ghosh, A., Bhatt, B. P., Zodape, S. T., and Patolia, J. S. 2009. Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions. *South African Journal of Botany*, 75 (2): 351-355.

Renaut, S., Masse, J., Norrie, J., Blal, B. and Hijri, M. 2019. A commercial seaweed extract structured microbial communities associated with tomato and pepper roots and significantly increased crop yield. *Microbial Biotechnology*, 12(6): 1346–1358.

Rioux, L. E., Turgeon, S. L., and Beaulieu, M. 2007. Characterization of polysaccharides extracted from brown seaweeds. *Carbohydrate Polymers*, 69(3): 530–537.

Salim, B. B. M. 2016. Influence of biochar and seaweed extract applications on growth, yield and mineral composition of wheat (*Triticum aestivum* L.) under sandy soil conditions. *Annals of Agricultural Sciences*, 61(2): 257-265.

Saravanan, S., Thamburaj, S., Veeraragavathatham, D., and Subbiah. A. 2003. Effect of seaweed extract and chloromequat on growth and fruit yield of tomato (*Lycopersicon esculentum* Mill.) *Indian Journal of Agricultural Research*, 37(2): 79–87.

Sarhan, T. Z. 2011. Effect of humic acid and seaweed extracts on growth and yield of potato plant (*Solanum tubersum* L.) Desire CV. *Mesopotamia Journal of Agriculture*, 39(2): 19-27.

Sarkar, G., Jatar, N., Goswami, P., Cyriac, R., Suthindhiran, K., and Jayasri, M. A. 2018. Combination of different marine algal extracts as biostimulant and biofungicide. *Journal of Plant Nutrition*, 41(9): 1163-1171.

Sethi, S. K., and Adhikary, S. P. 2008. Effect of seaweed liquid fertilizer on vegetative growth and yield of black gram, brinjal and tomato. *Seaweed Research and Utilization*, 30: 241-248.

Sharma, S.H.S., Lyons, G., McRoberts, C., McCall, D., Carmichael, E., Andrews, F., and McCormack, R. 2012. Bio-stimulant activity of brown seaweed species from Strangford Lough: compositional analyses of polysaccharides and bioassay of extracts using mung bean (*Vigno mungo* L.) and pak choi (*Brassica rapa chinensis* L.). *Journal of Applied Phycology*, 24: 1081–1091.

Shafeek, M. R., Helmy, Y. I., and Omar, N. M. 2015. Use of some bio-stimulants for improving the growth, yield and bulb quality of onion plants (*Allium cepa* L.) under sandy soil conditions. *Middle East Journal of Applied Sciences*, 5(1): 68-75.

Shukla, P., Mantin, E., Adil, M., Bajpai, S., Critchley, A., and Prithiviraj, B. 2019. Ascophyllum nodosum-based biostimulants: sustainable applications in agriculture for the stimulation of plant growth, stress tolerance, and disease management. *Frontiers in Plant Science*, 10: 655.

Slavik, M. 2005. Production of Norway spruce (*Picea abies*) seedlings on substrate mixes using growth stimulants. *Journal of Forest Science*, 51(1): 15–23.

Sulakhudin, S., Hatta, M., and Suryadi, U. E. 2019. Application of coastal sediments and foliar seaweed extract and its influence to soil properties, growth and yield of shallot in Peatland. AGRIVITA *Journal of Agricultural Science*, 41 (3): 450-460.

Sutharsan, S., Nishanthi, S., and Srikrishnah, S. 2014. Effects of foliar application of seaweed (*Sargassum crassifolium*) liquid extract on the performance of Lycopersicon esculentum Mill. in sandy regosol of Batticaloa District Sri Lanka. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 14(12): 1386-1396.

Sivasankari, S., Venkatesalu, V., Anantharaj, M., and Chandrasekaran, M. 2006. Effect of seaweed extracts on the growth and biochemical constituents of Vigna sinensis. *Bioresource Technology*, 97(14): 1745–1751.

Singh, S. K., Thakur, R., Singh, M. K., Singh, C. S., and Pal, S. K. 2015. Effect of fertilizer level and seaweed sap on productivity and profitability of rice (Oryza sativa). *Indian Journal of Agronomy*, 60(3): 69–74.

Siwik-Ziomek, A., and Szczepanek, M. 2019. Soil extracellular enzyme activities and uptake of N by oilseed rape depending on fertilization and seaweed biostimulant application. *Agronomy*, 9(9): 480.

Senthuran, S., Balasooriya, B. L. W. K., Arasakesary, S. J., and Gnanavelrajah, N. 2018. Effect of seaweed extract (Kappaphycus alvarezii) on the growth, yield and nutrient uptake of leafy vegetable Amaranthus polygamous. *Tropical Agricultural Research*, 30 (3): 81–88.

Tandel, K. V., Joshi, N. H., Tandel, G. M., Patel, M. R., and Tandel, J. T. 2016. Seaweed cultivation in India, a new opportunity of revenue generation. *Advances in Life Sciences*, 5(7): 2487-2491.

Thompson, B. 2004. Five years of Irish trials on biostimulants: the conversion of a skeptic. *USDA For Service Proceedings*, 33(2015): 72–79.

Temple, W. D., and Bomke, A. A. 1988. Effects of kelp (Macrocystis integrifolia) on soil chemical properties and crop response. *Plant and Soil*, 105 (2): 213-222.

Vernieri, P., Borghesi, E., Ferrante, A., and Magnani, G. 2005. Application of biostimulants in floating system for improving rocket quality. *Journal of Food Agriculture and Environment*, 3 (3): 86–88.

Veeragurunathan, V., Eswaran, K., Saminathan, K., Mantri, V. A., Malarvizhi, J., Ajay, G., and Jha, B. 2015. Feasibility of Gracilaria dura cultivation in the open sea on the South eastern coast of India. *Aquaculture,* 438: 68–74.

Venkataraman, K. V., and Mohan, V. R. 1997. Effect of seaweed extract SM3 on the cyanobacterium, Scytonema species. *Seaweed Research and Utilization,* 19: 13–15.

Wang, Z., Pote, J., and Huang, B. 2003. Responses of cytokinins, antioxidant enzymes, and lipid peroxidation in shoots of creeping bentgrass to high root-zone temperatures. *Journal of the American Society for Horticultural Science,* 128(5): 648– 655.

Wilson, S. 2001. Frost management in cool climate vineyards. In: University of Tasmania Research Report UT 99/1, Grape and Wine Research and Development Corporation.

Wite, D., Mattner, S.W., Porter. I. J., and Arioli, T. 2015. The suppressive effect of a commercial extract from Durvillaea potatorum and Ascophyllum nodosum on infection of broccoli by Plasmodiophora brassicae. *Journal of Applied Phycology,* 27(5): 2157–2161.

Zhang, X., and Ervin, E.H. 2008. Impact of seaweed extract-based cytokinins and zeatin riboside on creeping bentgrass heat tolerance. *Crop Science,* 48(1): 364–370.

Zhang, Q., Zhang, J., Shen, J., Silva, A., Dennis, D.A., and Barrow, C. J. 2006. A simple 96-well microplate method for estimation of total polyphenol content in seaweeds. *Journal of Applied Phycology,* 18: 445–450.

Zhu, J.K. 2000. Genetic analysis of plant salt tolerance using Arabidopsis. *Plant Physiology,* 124: 941–948.

Zodape, S.T., Gupta, A., Bhandari, S. C., Rawat, U. S., Chaudhary, D. R., Eswaran, K., and Chikara, J. 2011. Foliar application of seaweed sap as bio stimulant for enhancement of yield and quality of tomato (*Lycopersicon esculentum* Mill.). *Journal of Scientific and Industrial Research,* 70: 215–219.