

Review Article

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

Comment [AB1]: Title of the review is not appropriate. Need to modify it. It must be 'on' crop growth and soil. Not 'in' crop growth and soil.

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 viz. 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⁻¹ acre 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 yield *etc.*

Comment [AB2]: Kg acre⁻¹

Comment [AB3]: Abstract must be written conclusively mentioning the aim or objective of review, recent findings and future research thrusts. This manuscript seems like a report of a class room presentation or seminar. Need to improve to treat it as a review article

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 km² (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. Tamilnadu, 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)

Comment [AB4]: Need to start with briefing on seaweeds followed by seaweed extract

Comment [AB5]: Tamil Nadu

Comment [AB6]: Sentence not appropriate. Phaeophyta, Rhodophyta and Chlorophyta the three major groups of seaweeds

Comment [AB7]: Photographs of important species of seaweed may be incorporated with appropriate references

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 ₂ O ₅)	0.48 %
Potassium (K ₂ O)	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 germination of different crops

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 *Kappaphycus* or *Gracilara* seaweed sap at 15% concentration notably increased the germination in wheat. But, when the concentration is either below 2.5% or increased up to 20%, remarkably depletion in the germination (Dilvarnaik *et al.* 2017).

The higher concentrations of *Kappaphycus* 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 noticed 100% 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).

Comment [AB8]: At the end of the introduction part, there is a need to mention the need/objective of this review article

Comment [AB9]: It is not required to discuss the effect of seaweed extracts on germination, shoot growth and root growth under separate headings. It may be discussed under single heading as 'Effect of seaweed extracts on crop growth attributes'

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. alvarezii*@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. Mafakheri 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. *Kappaphycus* 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% *Kappaphycus* extract and it was statistically at par with 10 % and 5% *Kappaphycus* 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 (Kingham and Moore, 1982). *Ecklonia maximas* species extract also

Comment [AB10]: Many of the findings mentioned here as results of the experiments. Need to discuss on the findings with appropriate justifications/reasons/mechanisms behind the findings

content of auxins which is a 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 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 yields

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% *Kappaphycus* or *Gracilaria* extracts over the control (Layek *et al.* 2018). Application of either 10% concentration of *Kappaphycus* 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

Comment [AB11]: yield

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% *Kappaphycus 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 extract 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 hormone (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 plantations 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

Comment [AB12]: tomato plantation?

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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 trifoliolate orange, *Poncirus trifoliolate* (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⁺, Ca²⁺, Mg²⁺, 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 an organic fertilizer treatment for comparison in sweet corn. Soil electrical conductivity, potassium (K⁺), sulphate (SO₄²⁻), and active carbon (C) increased with seaweed addition relative to the organic fertilizer, whereas 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). Hellequinet *et al.* (2020) resulted that the biostimulant prepared from seaweed extracts induced changes in the soil stoichiometry with a greater content of NO₃⁻ and a lower content of PO₄³⁻ without impacting the soil content of NH₄⁺. Spraying seaweed extract 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). Senthuranet *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 extracts (*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 mycorrhizal 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·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 dSm⁻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-Woźniak, 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 (O₂⁻) 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 *si.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 extorts 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 were induced plant defence mechanism counter to pest and diseases of plants (Allen *et al.* 2001). The seaweed products enhance 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 seaweed extracts which helps in enhancing cereal, pulses, vegetables, fruit crop growth, yield and quality. The seaweed extracts stimulate soil microbial activity as well as improved the soil fertility, quality, increasing the nutrient use efficiency and mitigating drought, salinity and chilling injury. However, *Ulva*, *Durvillaea*, *Ascophyllum*, *Turbinaria*, *Gelidopsis* Spp. etc. creates disease resistance in crop.

Comment [AB14]: Need to rewrite the conclusion part.

References

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