Marine seaweeds (biofertilizer) significance in sustainable agricultural activities: A review

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Abstract. The marine environment provides adaptive conditions for many organisms, such as algae, shellfish, mussels, sponges, corals, and barnacles. There is a range of algae in Pakistan’s coastal waters, but, unfortunately, they are not used and are wasted. Efficient use of a valuable natural resource that can increase the efficiency of agricultural operations. Algae are abundant and easily found in a wet environment, either in seawater or freshwater. The seaweed and its products are extensively used in crops cultivation to enhance production systems due to many plant-growth-promoting compounds. It has been traditionally used for the fertilization of the fields since the ancient world. Some seaweeds and auxins, a plant hormone responsible for the vegetative growth and auxin-like compounds, have been found. Algae and their associated compounds can support the onset of seed germination and plant root growth, which applies to temperature, resistance to abiotic stress, and improves plants’ ability to absorb nutrients.

Keywords: algae, coastal, plant hormone, seaweed, sustainable plantation

1. Introduction
Seaweeds form a diverse and predominant group of photosynthetic organisms that plays a vital part in in aquatic ecosystems [1]. Seaweeds (also known as macroalgae) are aquatic plants belonging to the kingdom *Thallophyta* and considered an essential part of the marine ecosystem that inhabits the coastal regions [2]. Macroalgae have been estimated at 9000 species and mainly categorized into three groups [3]. There are three main groups of macroalgae based on the presence of photosynthetic pigment, storage food product and cell wall structure components, namely Phaeophyta (brown), Rhodophyta (red), and Chlorophyta (green) [3, 4]. Approximately 221 number of seaweeds species (Rhodophytes 125, Phaeophytes 64 and Chlorophytes 32) are using for commercial development worldwide, and out of 145 species are utilized as food, traditional medicines 24 species, almost 25 species in agriculture, including animal feed and compost [5]. Seaweed remains an underutilized marine ecosystem resource, although it has been utilized as a source of food, raw material for industries, therapeutic and botanical application for centuries [3].

The rapid growth of the human population globally compels us to think sustainable to fulfill agricultural activities. Several synthetic and chemicals used to increase crop yield and better growth of plants. Toxic elements such as inorganic pollutants and heavy metals exist in chemical fertilizers. These chemical fertilizers persisting application could induce the accumulation of these toxic pollutants in soil, deteriorating the soil ecological environment. Over time, macroalgae (seaweeds) are used as fertilizers,
being cost-effective and eco-friendly have shown a significant increase in crop yield globally [6]. The use of seaweeds and their extracts is vital in achieving sustainability in agriculture for their diverse resources and benefits for the plant’s growth and protection [7]. The recent rise in concerns about environmental problems triggered by the extensive use of synthetic fertilizers requires further studies to provide alternative strategies to mitigate such hazards [8]. Introducing organic fertilizer in modern cultivation activities tends to strengthen soil stability, and it would be an environmentally friendly approach [8]. The principal focus of this review is to highlight the implication of marine seaweeds as fertilizer, and it can play a key role in the rising demand for organic food. This review paper emphasizes the exploitation of seaweed and its extract in agricultural activities.

Due to the rapid and excessive use of synthetic fertilizers, the land resources of Pakistan are degrading at an alarming rate [15]. To sustain land quality with sustainable agricultural activities, using seaweed extracts in agriculture is a practical approach. In Pakistan, a total of 234 species of algae, among them 110 genera of seaweeds, are reported from the Balochistan coast, exhibiting a tremendous biological diversity, distributed among 57 families, 33 orders, 12 classes, and 6 divisions. Various types of seaweeds have been stated on the rocky shores of the Karachi coast [16]. In addition, the coastal waters around Sandpit, Manora, Hawkesbay, Buleji, Pacha, Paradise Point, Nathiagali, and Cape Monze accommodate a variety of marine benthic algae [17].

2. Potential of seaweeds as biofertilizers
Seaweed use as a biofertilizer reduces nitrogen and Phosphorous runoff, which increases the quality of water flowing in oceans and rivers [9]. The importance of seaweeds as compost has also been recognized in many territories. The possible ways of seaweeds’ exploitation in modern agriculture have been extensively explored. Different varieties of these marine algae preparations as liquid fertilizer and either whole or finely pulverized algal manures are being used [2]. Furthermore, fundamental advancements associated with seaweed extracts are better tolerance in relation to abiotic stresses, including drought, ion toxicity, freezing, and high temperature [10]. Sophisticated extraction methods, like microwave-assisted, pressurized liquid extraction, enzyme-assisted extraction, and supercritical fluid extraction, are presented for better utilization without deterioration [2]. A wide range of phytohormones is present in macroalgal extracts like Abscisic acid, Auxins, Betaine, Gibberellins, and Polyamines, along with micronutrients and trace elements act as a regulator of plant growth and enhance the crop reap when applied exogenously [7]. The seaweed fertilizer application on crops showed significant expansion and increased crop production [11–13].

The coastline of Pakistan has stretched 1,050 km, starting from Jiwani near Iran border in the west to Sir Creek, India in the East and consist of various geomorphic features such as terraces, rocky beaches, mudflats, cliffs, and headlands. Pakistan coastal waters have various and rich algal reserves due to a warm atmosphere and upwelling of nutrient-rich water [14].

| Species Name                  | Common Name         |
|-------------------------------|---------------------|
| *Melanothamnus* [18]          | Red Seaweed         |
| *Spatoglossum variable*       | Brown seaweed       |
| *Stokeyia indica*             | Brown seaweed       |
| *Ulva fasciata*               | Green seaweed       |
| *Colpomenia sinuosa*          | Brown seaweed       |
| *Padina tetrastromatica*      | Brown seaweed       |
| *Stoechospermum marginatum*   | Brown seaweed       |
| *Enteromorpha intestinalis*   | Green seaweed       |
3. Main composition of seaweeds

The seaweeds contain organic matters and specific nutrient content that stimulate plant growth [19]. It was also shown that adding up different seaweeds in sufficient quantities enhanced soil conditions and growing parameters in field harvests [15]. The essential nutrients like Nitrogen (N), Phosphorous (P), and Potassium (K) improve the level of the soil. A high diversity of polysaccharides are extraordinary in diverse marine algae.

### Table 2. Marine algae elemental composition from the coastal areas of Karachi in ppm

| Marine algae          | Ca    | Cd    | Co    | Cr    | Cu    | Fe    | K     | Mg    | Na    | Pb    | Zn    |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Chlorophyta           | 32312.5 | 1.84  | 5.92  | 8.65  | 9.9   | 2186.25 | 54853 | 12366.58 | 67977.5 | 23.47  | 33.93 |
| Bryopsis pennata      | 80800 | 3.15  | 8.05  | 9.925 | 12.9  | 3795  | 10855 | 6660  | 28535 | 43.875 | 37.425 |
| Lamour               | 70300 | 2.2   | 6.8   | 12.525 | 11.25 | 2542.5 | 19625 | 764.5  | 155950 | 23.675 | 21.725 |
| Caulerpa racemosa     | 14755 | 0.975 | 4.0   | 10.425 | 8.5   | 2840  | 15810 | 6870  | 110400 | 19.1   | 25.05 |
| Caulerpa taxifolia    | 14730 | 1.925 | 9.55  | 2.825  | 5.65  | 862.5 | 231700 | 9605  | 26.075 | 18.25  |          |
| Codium                      | 4745  | 0.5   | 0.5   | 23.325 | 14.0  | 2695  | 18590 | 13400 | 19.6   | 81.55  |          |
| Enteromorpha intestinalis(L.) Nees | 8545  | 2.3   | 2.3   | 1.85   | 7.125 | 3250  | 36900 | 36900 | 8.55   | 19.15  |          |
| Phaeophyta             | 27351.6 | 2.67  | 6.16  | 7.01   | 9.7   | 673.5 | 68470.33 | 16030.33 | 36998.23 | 10.05   | 117.63 |
| Cystoseira indica      | 19050 | 3.95  | 5.125 | 4.7    | 8.125 | 249   | 118125 | 9425  | 80562.5 | 8.1    | 33.625 |
| Padina tetrastromatica Hauck | 46950 | 2.875 | 6.375 | 16.15  | 12.38 | 3105  | 26620 | 24500 | 20530  | 15.25  | 44.475 |
| Sargassum vulgare      | 16055 | 1.2   | 7     | 0.18   | 8.6   | 1740  | 60666 | 14166 | 9902.2 | 6.8    | 274.8  |
| Rhodophyta             | 12548.2 | 2.22  | 5.81  | 5.51   | 9.14  | 70196.4 | 47923.57 | 13721.78 | 119177.78 | 12.06   | 29.47  |
| Botryocladia leptopoda (J.Ag.) Kylin | 9055  | 2.9   | 8.05  | 3.4    | 13.6  | 499.5 | 65925 | 2740  | 202375 | 7.2    | 26.375 |
| Hypnea musciformis (Wulf) Lamour | 7977.5 | 1.975 | 5.1   | 2.325  | 6.675 | 230.5 | 62125 | 4930  | 129687.5 | 3.85   | 15.675 |
| Sarcosoma valenciae (Turn.) Mont. Sarconema furcellatum Zanard Scinaia saifulahii Afaq et Shamee Solieria robusta (Grev.) Kylin | 10350 | 2.7   | 7.75  | 10.625 | 11.63 | 1825  | 112937.5 | 15260 | 154187.5 | 14.1   | 29.925 |
| Botryocladia leptopoda (J.Ag.) Kylin | 7447.5 | 2.55  | 7.45  | 5.425  | 12.7  | 340.75 | 136375 | 19820 | 220187.5 | 16.05  | 20.775 |
| Solieria robusta (Grev.) Kylin | 8350  | 1.15  | 2.85  | 4.55   | 4.2   | 1070  | 14925 | 12350 | 18690  | 13.45  | 47.875 |
| Average amount        | 22735.47 | 2.165 | 5.893 | 7.372  | 9.531 | 1527.015 | 64119.75 | 13646.44 | 97006.543 | 15965  | 47.646 |
Table 3. Mineral composition of three genera of algae [2].

| Mineral compounds (pg/g of extract) | Red alga (Lithothamnion calcareum) | Green alga (Ulva lactuca) | Brown alga (Stoechospernum marginatum) |
|-------------------------------------|-------------------------------------|---------------------------|----------------------------------------|
| Copper                              | 4.89                                | 0.38                      | 8.64                                   |
| Manganese                           | 57.50                               | 62.00                     | 8.75                                   |
| Zinc                                | 15.80                               | 1.01                      | 19.92                                  |
| Iron                                | 915.00                              | 0.37                      | 858.50                                 |
| Potassium                           | 5.17                                | 113.00                    | 29.65                                  |
| Magnesium                           | 25.80                               | 18.30                     | 9.60                                   |
| Cobalt                              | 0.80                                | 0.06                      | 3.47                                   |
| Chromium                            | 0.82                                | nd*                       | 16.60                                  |
| Lead                                | 0.15                                | nd*                       | 0.40                                   |
| Nickel                              | 1.84                                | 10.40                     | 25.20                                  |
| Cadmium                             | 0.07                                | 2.00                      | 5.90                                   |
| Sodium                              | 4.15                                | 185.00                    | 39.11                                  |
| Calcium                             | 351.50                              | 195.26                    | 2053.43                                |

*ND = Not detected

Table 4. Carbohydrates and amino acid composition of algae [2].

| Polysaccharides                      | Red algae (Rhodophyceae) | Green algae (Chlorophyceae) | Brown algae (Phaeophyceae) |
|--------------------------------------|--------------------------|----------------------------|---------------------------|
| Agars, agaroids                      |                          |                            |                           |
| Carrageenans                         |                          |                            |                           |
| Cellulose                            |                          |                            |                           |
| Complex mucilage’s                   |                          |                            |                           |
| Furcellaran                          |                          |                            |                           |
| Glycogen (floridean starch)          |                          |                            |                           |
| Mannan                              |                          |                            |                           |
| Xylans, rhodymenan                   |                          |                            |                           |
| Pectin                               |                          |                            |                           |
| Sulfated mucilages                   |                          |                            |                           |
| Xylans                               |                          |                            |                           |
| Amino acids                          |                          |                            |                           |
| Alanine                              | + + +                    | + + +                      | + +                       |
| Glycine                              | + + +                    | + + +                      | + +                       |
| Valine                               | + +                      | + + +                      | + +                       |
| Leucine                              | + +                      | + + +                      | + +                       |
| Isoleucine                           | + +                      | + + +                      | + +                       |
| Serine                               | + +                      | + + +                      | + +                       |
| Threonine                            | + + +                    | + + +                      | + +                       |
| Cysteine                             | + +                      | + + +                      | + +                       |
| Methionine                           | + +                      | + + +                      | + +                       |
| Aspartate                            | + + +                    | + + +                      | + +                       |
| Glutamate                            | + + +                    | + + +                      | + +                       |
| Lysine                               | + + +                    | + + +                      | + +                       |
| Arginine                             | + + +                    | + + +                      | + +                       |
| Phenylalanine                        | + + +                    | + + +                      | + +                       |
| Tyrosine                             | + + +                    | + + +                      | + +                       |
| Proline                              | + + +                    | + + +                      | + +                       |
| Histidine                            | + + +                    | + + +                      | + +                       |

*++ *++ High quantity > 60 mg/g total nitrogen;
*+* + Average quantity 20-60 mg/g;
*+* + Low quantity <20 mg/g;
4. Discussion

4.1 Application of seaweed in agriculture

Seaweed use as manure in agriculture has been practiced since ancient times. For the last thirty years, it has been excessively utilized as fertilizer. They are applied as whole or finely chopped manure or liquid extract. The recent liquid extract is getting more attention as a foliar spray for generating more rapid crop yield in vegetable, fruits, and cereal crops [20]. Studies reveal that the foliar application method is considered more effective than other supplying nutrients methods to plant through soil [21]. Unlike chemical fertilizers, seaweed extracts are supposed to use as biologically degradable, non-toxic, non-polluting, and non-hazardous [22]. The introduction of organic farming and the demand for organic food products has enabled the application of seaweed as a biofertilizer, biostimulant, and soil conditioner [2]. Huge algal stock is present along the Pakistan coast but not efficiently utilized. Sustainable utilization of these resources can provide livelihood and improve economic condition along with sustainable agricultural activities [14].

4.2 Effect on crop yield

The seaweeds used as manure in farming practice are very ancient and common among the Romans and practiced in France, Britain, Japan, and China. The marine macro-algae use as fertilizer in crop yield has a long tradition in coastal areas worldwide. Seaweed remained important to farmers, even in the early 1900s. In many countries, seaweed and beach cast are still used in agriculture and horticulture [20]. Foliar application of seaweed extract [11] on the onion field showed a significant increase in the crop yield, though the low conc. of 0.5% induced maximum plant growth, nutrient uptake, and quality yield [11]. Some different species of seaweed were applied on rice fields, which positively influenced crop yield [23]. Ascophyllum nodosum is recognized as the most successful and widely utilized seaweed extract, which acts as a biostimulant for better crop yield. It contains growth-stimulating elements like vitamins, micronutrients, oligosaccharides, and phytohormones [10]. It is anticipated that the liquid seaweed use as fertilizer enhances the crop yield by about 20-30%, contrasted to the untreated plantation [24].

4.3 Abiotic stressors

Studies reveal that certain abiotic factors such as drought, temperature, and salinity have an irreversible effect on plants and reduce major crop production. Projected by the year 2050, 50% of the arable land would be salinized, having a drastic impact on worldwide agriculture production [3].

4.4 Biotic stressors

Seaweeds are considered a powerful source of natural molecules. Seaweeds can make high amounts of secondary metabolites: terpenes, lipid-, steroid-, and aromatic-like compounds, acetogenins, phlorotannin, amino acid-derived products, and other polymeric substances. Marine algae also produce bioactive metabolites in response to microbial activities [2].

Seaweed extracts indicated improved plant defense against pest and diseases. Plants defend themselves against pathogen invasion by the signal molecules perception consists of a wide variety of molecules such as peptides, polysaccharides and oligo, lipids, and protiens, often found in the harming pathogens cell wall [3].

Seaweed and their effects on disease control need more comprehensive analysis and assessments in various aspects in the future. Thorough studies on the stimulation of systemic resistance in addition to direct inhibition of pathogen need to be conducted. For example, biocontrol active Bacilli which has been demonstrated that antibiologically active secondary metabolites not only inhibit phytopathogens but are also able to activate plant resistance structures.

4.5 Effect on plant growth

The use of seaweed extracts has shown encouraging effects in plant growth and development by stimulating seed germination, root development, increased nutrient uptake, and enhanced frost
resistance in adverse conditions [25]. The foliar application of seaweed extract stimulated maize seedlings’ growth, showing a significant increase in root and shoot development [26]. Seaweeds improve the number of soil nutrients like N, P, and K and other minerals necessary for plant growth [2]. The composition of elements present in seaweed has been collected from the coast of Karachi which was detected as Ca, Cr, Cd, Cu, Na, Pb, K, Mg, Co, Zn, and Fe. The most abundant elements were Na, K, Ca, Fe and Mg [17]. The presence of trace elements indicates the potential to be utilized in agricultural activities, as they are considered plant growth-promoting elements [27].

4.6 Effect on soil condition
The increasing demand of organic fertilizers to meet the requirement of organic farming, seaweeds are considered as potential biofertilizers for conditioning of soil [2]. Seaweed (such as Ascophylum nodosum) have been widely used as soil conditioner and mineral source for plants [28]. Application of liquid seaweed extract shows better plant growth and soil texture. Improved soil structure leads to enhanced aeration, improved nitrogen fixation. Due to raised capillary action, increased root system growth is observed [29].

4.7 Recovery of polluted soil
Heavy metal contamination and its pollution is one of the most major environmental problems today. Several industries release untreated effluent containing a number of pollutants, including heavy metals, into the environment, such as textile effluent, electroplating industry, automotive sector, sugar industry, pharmaceutical, metallurgy, iron and steel, electro-osmosis, tannery, paper industry, mining, beverages industry, and food industry etc. Thus, heavy metal does not degrade and becoming a source of persistent environmental pollution, threatening human health and habits. There are various kind of heavy metals and classified into three main categories consist of toxic metals (such as Pb, As, Hg, Ni, Cr, Cu, Sn etc.), precious metals (such as Ru, Ag, Pd, Pt etc.) and radionuclides (such as Am, Ra, Th, U etc.) [30]. Therefore, seaweeds present great prospects for biosorption because their macroscopic composition provides an appropriate basis for the production of biosorbent particles suitable for applications as sorption material. Studies reveal that DDT [1,1,1-trichloro-2,2-bis (p-chlorophenyl) ethane], which is a substantial environmental pollutant, is progressively biodegraded after applying seaweed extracts. Probably, it is due to the high level of dissolved organic carbon present in soil modified with seaweed, which significantly increases DDT biodegradation [2]. Kappaphycus sp were applied as biosorbent for removal of heavy metals (Pb, Cu, Fe, Zn) showed significant results. It was concluded that seaweed is a potential biosorbent for the removal of heavy metals from the environment [31]. As seen in the results, it may be concluded that G. corticata varcartecala and G. lithophila are potential algal species for effective removal of heavy metals, namely Cr (III), Cr (VI), Pb (II), Hg (II), Pb (II) and Cd (II) from environmental sources. The biosorption of heavy metals Cu and Zn by green macroalgae (Chaetomorpha linum) was conducted. It was considered an alternative technique for managing unwanted biological materials using processed algal material [32].

5. Conclusion
Seaweeds is considered as an underutilized resource that needs to be fully employed. Seaweeds not only enhance plant growth but also provide resistance against biotic and abiotic stressors. The utilization of chemical/synthetic fertilizers led to soil degradation, health, and environmental hazards. To meet the global food demand, seaweeds provide an organic substitute for fertilizer to increase crop yield. The requirement for seaweed extract is increasing day by day due to its low cost and eco-friendly.

References
[1] Egan S, Harder T, Burke C, Steinberg P, Kjelleberg S and Thomas T, “The seaweed holobiont: Understanding seaweed-bacteria interactions,” FEMS Microbiol. Rev., 37, 3, pp. 462–476, 2013, doi: 10.1111/1574-6976.12011.
[2] Nabti E, Jha B and Hartmann A, “Impact of seaweeds on agricultural crop production as
biofertilizer,” *Int. J. Environ. Sci. Technol.*, **14**, 5, 1119–1134, 2017, doi: 10.1007/s13762-016-1202-1.

[3] Khan W *et al.*, “Seaweed extracts as biostimulants of plant growth and development,” *J. Plant Growth Regul.*, **28**, 4, 386–399, 2009, doi: 10.1007/s00344-009-9103-x.

[4] Dhargalkar V K and Kavlekar D, “Seaweeds – A field Manual,” *Nat. Inst. Oceanogr. Dona Paula, Goa.*, **403** 004, p. 36, 2004.

[5] Zemke-white W L and Ohno M, “World seaweed utilization : An end-of-century summary . J Appl Phycol World Seaweed utilization : An end-of-century summary,” no. March, 2014, doi: 10.1023/A.

[6] Giri B, Prasad R and Wu Q, *Biofertilizers for Sustainable Agriculture and Environment*, no. September, 2019.

[7] Panda D, Pramanik K and Nayak B R, “Use of Sea Weed Extracts as Plant Growth Regulators for Sustainable Agriculture,” *Int. J. Bio-resource Stress Manag.*, **3**, 3, 404–411, 2012.

[8] Brtnicky M *et al.*, “Long-term effects of biochar-based organic amendments on soil microbial parameters,” *Agronomy*, **9**, 11, 1–17, 2019, doi: 10.3390/agronomy9110747.

[9] Abdel-Raouf N, “Agricultural importance of algae,” *African J. Biotechnol.*, **11**, 54, 11648–11658, 2012, doi: 10.5897/ajb11.3983.

[10] Wally O S D *et al.*, “Regulation of Phytohormone Biosynthesis and Accumulation in Arabidopsis Following Treatment with Commercial Extract from the Marine Macroalga Ascophyllum nodosum,” *J. Plant Growth Regul.*, **32**, 2, 324–339, 2013, doi: 10.1007/s00344-012-9301-9.

[11] Abbas M *et al.*, “Effect of seaweed extract on productivity and quality attributes of four onion cultivars,” *Horticulturala*, **6**, 2, 2020, doi: 10.3390/horticulturae6020028.

[12] Renault S, Massé J, Norrie J P, Blal B and Hijri M, “A commercial seaweed extract structured microbial communities associated with tomato and pepper roots and significantly increased crop yield,” *Microb. Biotechnol.*, **12**, 6, 1346–1358, 2019, doi: 10.1111/1751-7915.13473.

[13] Abdel A M R, Tantaway A S, Hafez M M, and Habib H A M, “Seaweed Extract Improves Growth, Yield and Quality of Different Watermelon Hybrids,” *Res. J. Agric. Biol. Sci.*, **6**, 2, 161–168, 2010, [Online]. Available: https://www.researchgate.net/publication/265579507.

[14] Ali A *et al.*, “Standing stock of seaweeds in submerged habitats along the karachi coast, pakistan: An alternative source of livelihood for coastal communities,” *Pakistan J. Bot.*, **51**, 5, 1819–1830, 2019, doi: 10.30848/PJBJ2019-5(2).

[15] Badar R, Khan M, Batool B and Shabbir S, “Effects of organic amendments in comparison with chemical fertilizer on cowpea growth,” *Ijar*, **1**, 45, 66–71, 2015, [Online]. Available: www.allresearchjournal.com.

[16] P. 78. *A Handbook on Pakistan’s Coastal and Marine Resources*. MFF Pakistan, Copyright : 2016.

[17] Rizvi M, Farooqui S, Khan M and Shameel M, “Elemental Composition and Bioactivity of Seaweeds from Coastal Areas of Karachi, Pakistan,” *J. King Abdulaziz Univ. Sci.*, **12**, 1, 209–215, 2001, doi: 10.4197/mar.12-1.15.

[18] Baloch G N, Tariq S, Ehteshamul-Haque S, Athar M, Sultana V, and Ara I, “Management of root diseases of eggplant and watermelon with the application of asafoetida and seaweeds,” *J. Appl. Bot. Food Qual.*, **86**, 1, 138–142, 2013, doi: 10.5073/JABFQ.2013.086.019.

[19] M. Davari, S. Niwas Sharma, and M. Mirzakhani, “Residual influence of organic materials, crop residues, and biofertilizers on performance of succeeding mung bean in an organic rice-based cropping system International Journal Of Recycling of Organic Waste in Agriculture,” *Int. J. Recycl. Org. Waste Agric.*, **1**, 1999, p. 14, 2012.

[20] G. Thirumaran, M. Arumugam, R. Arumugam, and P. Anantharaman, “Effect of Seaweed Liquid Fertilizer on Growth and Pigment Concentration of Abelmoschus esculentus (l) medikus,” *Am. J. Agron.*, **2**, 2, 57–66, 2009.

[21] M. Begum, B. C. Bordoloi, D. D. Singh, and N. J. Ojha, “Role of seaweed extract on growth, yield and quality of some agricultural crops: A review,” *Agric. Rev.*, **39**, 321–326, 2018, doi: 10.18805/ag.r-1838.
[22] D. Altındal, Effects of seaweed extract (se) applications on seed, *Int J of Agriculture, Forestry and Life Sciences* **3**, 1, 115–120, 2019.

[23] S. Sunarpi, A. Jupri, R. Kurnianingsih, N. I. Julisaniah, and A. Nikmatullah, “Effect of seaweed extracts on growth and yield of rice plants,” *Nusant. Biosci.*, **2**, 2, 73–77, 1970, doi: 10.13057/nusbiosci/n020204.

[24] N. Ashok Kumar, B. Vanlalzarzova, S. Sridhar, and M. Baluswami, “Effect of liquid seaweed fertilizer of Sargassum wightii grev. on the growth and biochemical content of green gram (Vigna radiata (L.) R. wilczek),” **4**, 4, 40–45, 2012, [Online]. Available: http://recent-science.com/.

[25] A. Mishra, S. Sahni, S. Kumar, and B. D. Prasad, “Seaweed - An Eco-friendly Alternative of Agrochemicals in Sustainable Agriculture,” *Curr. J. Appl. Sci. Technol.*, no. September, pp. 71–78, 2020, doi: 10.9734/cjast/2020/v39i2730921.

[26] I. Jeannin, J. C. Lescure, and J. F. Morot-Gaudry, “The Effects of Aqueous Seaweed Sprays on the Growth of Maize,” *Bot. Mar.*, **34**, 6, 469–474, 1991, doi: 10.1515/botm.1991.34.6.469.

[27] P. W. Haluschak *et al.*, *Status of Selected Trace Elements in Agricultural Soils of Southern Manitoba*. 1998.

[28] V. G. Allen *et al.*, “TASCO: Influence of a brown seaweed on antioxidants in forages and livestock-A review,” *J. Anim. Sci.*, **79**, no. November, pp. E21–E31, 2001, doi: 10.2527/jas2001.79E-SupplE21x.

[29] S. T. Zodape, “Seaweeds As a Biofertilizer,” *J. Sci. Ind. Res. (India)*, **60**, 5, 378–382, 2001.

[30] J. Lin, H. Li, W. Huang, W. Xu, and S. Cheng, “A Carbon Footprint of High-Speed Railways in China: A Case Study of the Beijing-Shanghai Line,” *J. Ind. Ecol.*, **23**, 4, 869–878, 2019, doi: 10.1111/jiec.12824.

[31] M. S. Rahman and K. V. Sathasivam, “Heavy metal adsorption onto kappaphycus sp. from aqueous solutions: The use of error functions for validation of isotherm and kinetics models,” *Biomed Res. Int.*, vol. 2015, 2015, doi: 10.1155/2015/126298.

[32] L. C. Ajabi and L. Chouba, “Biosorption of Cu2+ and Zn2+ from aqueous solutions by dried marine green macroalga Chaetomorpha linum,” *J. Environ. Manage.*, **90**, 11, 3485–3489, 2009, doi: 10.1016/j.jenvman.2009.06.001.