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Seaweed effects on plant growth and environmental remediation: A review

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ABSTRACT

Seaweeds are plants found in the sea that have tremendous applications in the fields of agriculture and environment. It comprises three giant classes with a large number of different species and their ability to adapt to the various conditions qualifies them more applicable to various environmental and agricultural arena. Agriculturally, both three classes *Phaeophyta*, *Rhodophyta* and *Chlorophyta*, have significant roles in promoting plant growth and productivity and soil protection as well as its reclamation with class *Phaeophyta* have the highest contribution due to its alginic acid content and other multifaceted components that are higher followed by *Rhodophyta* and *Chlorophyta*. Seaweed (living or dead biomass) has the ability to phytoremediate environment against heavy toxic metals and lessen the excessiveness of non-metal inorganic elements via physisorption, chemisorption with the aid of binding sites provided by proteins and carbohydrates functional groups existing in their cell walls and secretion of organic acids and intracellular transformation and accumulation. Seaweed is an important factor in environmental remediation and soil restoration processes

KEYWORDS: Seaweeds, plant growth, soil revival, drought, phytoremediation

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The universal anthropogenic activities and negative climatic vagaries have established a rise in atmospheric pollution and temperature, salinization of soil, and metal toxicity and these evoke diminished agricultural production effects and the grade of the crop (Dos Reis *et al.*, 2012) and animals and humans wellbeing. Any environmental contaminations are available to detriment of the lives of a surrounding organism. Seaweed also called marine/macroalgae are non-flowering primitive, photosynthetic macrophytes and naturally renewable found in oceans around the tidal regions that occupies up to 71% of the world. Green, brown and red seaweeds are widely spread in the tidal, intertidal and subtidal areas respectively (Rao *et al.*, 2018). Macroalgae are bigger, having a simple thallus structure without true leaf and roots, they have pseudo roots known as hold fasts/rhizoids. Algae possess chlorophyll-a, b, c and contain protein, carbohydrate and other plant products akin to those of higher plants. They do photosynthesis through their thallus (Dawson *et al.*, 1966; Goecke *et al.*, 2010). Algae are considered as a primary source of organic compound in an aquatic environment and hence it plays a crucial role in the food chain (Shalaby, 2011). According to Okolie *et al.* (2018)

seaweeds are macroscopically multi-cellular organisms that dwell in coastal, marine ecosystems and are the wellspring of enzymes, polyunsaturated fatty acids, polysaccharides, bioactive peptides, among others. They supply the oxygen required for the metabolism among the consuming organisms. Additionally, macroalgae have been evidenced to procure a rich source of natural bioactive compounds with hypolipidemic, anti-inflammatory, antioxidant, hypercholesterolemia, anti-neoplastic, antifungal, antiviral and antibacterial properties (El-Baroty *et al.*, 2017). The ability to adapt, grow effectively and potential to serve as additives in food, bio-fertilizer, sodic soil refining, and important source of biofuel are few amongst macroalgal distinguishing features.

Algae come in sizes from as small as 1 µm to macro-sized seaweeds that may enlarge to over fifty meters (Pereira *et al.*, 2021). According to Aslam *et al.* (2010) red algal extract (*Lithothamnion calcareum*) has substantial mineral content and this leads to its utilization in animal and human food. Shalaby (2011) coined out that, seaweed consists of remarkable secondary metabolites such as phenolic compounds,

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unsaturated fatty acids, carotenoids, phycobiliprotein pigments, polysaccharides. Some of the natural algal products were proven to have different biological activities, including anticancer activity, antioxidant activity, antimicrobial activities against virus, bacteria, and fungi, bioremediation potentials and organic fertilizer. Majority of these compounds are produced in macroalgae at the last stage of their growth and/or as a result of environmental stress inducing some alterations in metabolic pathways. The potential for seaweed has been studied in the agricultural sector and the need to explore the more potentialities is of great advantage. According to Nabti *et al.* (2016) macroalgae are rich in diverse compounds like antimicrobial compounds and minerals, phytohormones, osmoprotectants, lipids, proteins, carbohydrates and amino acids. The advantages of agricultural applications of seaweed are numerous and diverse including frost and saline resistance, fertilization, improving health and growth of plants namely shoot and root elongation, improved water and nutrient uptake, stimulation of seed germination, biocontrol and resistance toward phytopathogenic organisms and remediation of pollutants in contaminated soil (Nabti *et al.*, 2016). Macroalgae have such ability to reduce uptake of contaminants at the same supply nutrient for plants' development. Integrating soil with seaweed rise plant micro- and macronutrients and improve soil biological and physicochemical properties (Khan *et al.*, 2009). The application of algae to remediate environmental contamination known as phycoremediation is a trending issue round the globe. Through photosynthesis, algae fix abundant CO₂ and eradicate excess nutrients effectively at a minimal cost also harmful materials and pathogens are removed from waste water. Xenobiotics, heavy metals and other chemicals are known to be depolluted, altered, accumulated or volatilized by algal metabolism (Sunday *et al.*, 2011). This review paper aimed at exploring the role macroalgae plays in improving plant growth and development, quality of plant product, preventing topsoil, relieve abiotic stress and remediation of environmental contaminants.

USE AS FERTILIZER AND SOIL REVIVAL

Food demand is among the foremost issues that attract global attention due to rapid population growth and plant growth slows down drastically due to a decrease in soil fertility and the ability to support the growth of different plants species. Deficiency in macro and micronutrients, soil pH amongst others are the major contributing factors. Inorganic fertilizer has been reported to pollute the environment, hence the need to devise other means to supplement nutrients required for plant growth and development. It has been reported that, along the coastal regions, seaweed has been applied to amend the soil either directly or in the composted form to achieve excellent crop production and where there is nutrient insufficiency to reclaimed alkaline soils (Zodape, 2001; Craigie, 2011). One distinguishing benefit of seaweed is their ability to condition the soil and be used to green manure (Rao *et al.*, 2018). Previous researches have proved that Seaweed Fertilizer (SF) is better and eco-friendly than other chemical fertilizers (Anantharaj & Venkatesalu, 2002) as no pollution is reported upon the use

of green manure. Seaweed potential to supplement soil with the macronutrients such as Magnesium, Calcium, Potassium, Phosphorus, Nitrogen, Sulfur, plant growth regulators; Cytokinins, Auxins and Gibberellins and trace elements like Cu, Zn, and Mn has been documented (Rengasamy, 2004). When applied to flowers, crops, vegetables and fruit, some improvements included increased nutrients uptake, higher yields, improved vigor, increased level of resistance to some pests and diseases, the extended shelf life of fruit, seed germination enhancement, and improved defense against abiotic stresses (Chatzissavvidis & Therios, 2014). Seaweed manure is proven to be more important than chemical fertilizers due to its richness in organic matter, help in retaining moisture and adding minerals as well as making them accessible to plant roots in the upper soil level (Jothinayagi & Anbazhagan, 2009). Raghunandan *et al.* (2019) reported that presence of fatty acid, carbohydrate and protein in seaweed facilitates nutrient and moisture retention in the soil which in turn improve soil texture and stimulate activities of soil microorganisms.

A significant quantity of alginate in brown algae which contains complex chains helps to anchor topsoil tightly together thus preventing soil losses. Seaweed-based manure establishes a good environmental condition for root growth by promoting microbial activities such as mineralization of nutrients and mobilization as well as favoring microbial diversity formation (Selvaraj *et al.*, 2004; Battacharya *et al.*, 2015). Soil reaction can be considered a crucial factor that triggers multiform of other proprieties of soil and positive effect to plant growth. The activity of microorganisms, availability and solubility of nutrients are some of the most crucial processes which indeed depend on pH. The cell wall matrix of *Rhodophytes* consist of sulphated galactan which serves as a protective cover against extreme changes in pH, temperature and salinity of soil (Lim *et al.*, 2018). Sen *et al.* (2014) established that utilization of *Ascophyllum spp.* as a conditioner to soil averts losses of soil's top. *Nostoc muscorum* promotes stability in saline soil, where mostly soil aggregation is attributed to the release of exopolysaccharide by microorganisms or supplemented to the soil after death and cellular lysis (Singh, 2014). It has been reported that brown seaweed *sargassum* is valuable manure since they contain a significant amount of alginate which serves as a soil conditioner and alginic acid that accelerate the decomposition of organic matter by bacteria thereby increasing soil humus and nutrient (Zodape, 2001). Alginate and humic acid present in seaweed contribute to the formation of soil aggregate in the nonporous soil containing clay with minimum organic material. Soil aggregate provide more space for air, water, shelter for microorganisms and circulation of nutrient.

PLANT STRESS ALLEVIATION

Abiotic stresses including temperature (heat and cold), salinity and drought are universal problem distressing land overtop 800 million hectares, result in the immensely negative impact to plant productivity (Ferchichi *et al.*, 2018). Various abiotic factors such as temperature salinity, and drought, are displayed as osmotic stress and this trigger secondary effects such as

oxidative stress, resulting in accumulation of reactive oxygen species (ROS) like superoxide anion ($O_2^{\cdot-}$) and hydrogen peroxide (H_2O_2) (Mittler, 2002; Khan et al., 2009).

Saline soils are the soils that contain a significant amount of sodium salt mainly Na_2SO_4 or $NaCl$ whereas $NaHCO_3$ and Na_2CO_3 found in alkaline soil both of which have an influential effect on the soil properties (Singh & Dhar, 2010). The ability of salt stress to cause a drastic decline in vegetative growth, yield and quality of fruit has been established (Hegazi et al., 2014). Seaweeds provide excellent bioactive materials useful for salinity stress alleviation. Slight stress due to salinity could inflict blighting water–cell relations, physiological drought in plants, impairment of cell expansion, and consequential growth fare reduction (Hasegawa et al., 2000). In alkaline soil, both soluble and solid salts are found in higher concentrations which results in osmotic pressure leading to poor quality agricultural products. Prolong exposure time to elevated salinity result in ionic stress creating a disturbance in the intracellular ions homeostasis, which induce dysfunction of membrane and metabolic activity diminution and growth inhibition, and impose cell death (Hasegawa, 2013). High osmolarity inhibits plant growth-promoting rhizobacteria activity which in turn affects plant growth and productivity. Previous studies proved that the application of a number of kinds of *Ascophyllum* species improved salinity stress tolerance in many plants (Bonomelli et al., 2018; Jolinda et al., 2018). *A. nodosum*, enhances the accumulation of antioxidants, minerals, and essential amino acids in tomato fruits grown under salinity stress. It has reported been by Abdel-Latef et al. (2017) that *Sargassum muticum* and *Jania rubens* seaweeds have the ability to ameliorate sodium chloride salt stress in chickpea. According to Subramanian et al. (2011) alginate, diverse polysaccharides and some sulphated compounds were depicted to trigger directly the growth of root and indirectly guild with microbes and energize the plants' defensive mechanisms and persuade genes involve in pathogenesis-related defense in plants (Vera et al., 2011). The calcareous red seaweeds algae, *L. corallioides* and *P. calcareum* are applied to neutralize acid soils, as an agricultural lime substitute (McHugh, 2003).

Drought the global concern about the availability of water for agricultural use is has been increasing. Amongst abiotic stresses, drought is one of the foremost issues decreasing crop productivity in many parts of the world (Farooq et al., 2009). Plant physiology and crop productivity have been affected by drought stress (Table 1). Drought affects plants by inducing

Table 1: Algal species for alleviation of soil salinity stress for some crops

Seaweed Spp.	Crop	Reference
<i>A. brasilense</i>	<i>V. faba</i>	(Hamaoui et al., 2001)
<i>A. brasilense</i>	<i>C. arietinum</i>	(Hamaoui et al., 2001)
<i>H. diazotrophicus</i>	<i>H. vulgare</i>	(Suarez et al., 2015)
<i>A. chroococcum</i>	<i>Z. mays</i>	(Rojas-Tapias et al., 2012)
<i>A. brasilense</i>	<i>L. sativa</i>	(Fasciglione et al., 2015)
<i>P. dispersa</i>	<i>C. annuum</i>	(Del Amor et al., 2012)
<i>Brasilense/P. dispersa</i>	<i>C. annuum</i>	(Nair et al., 2012)
SWE	<i>A. thaliana</i>	(Nair et al., 2012)

the production and accumulation of abscisic acid (ABA) which regulates closure of stomata causing impairment in the photosynthetic pathway (Chaves et al., 2009). Due to the complex metabolic pathways involved in drought tolerance, very little achievement was attained in generating drought-tolerant crop varieties by means of genetic engineering. Hence, devising biological processes to alleviate drought stress in plants is the better alternative. The use of seaweed extracts can alleviate production decline through the improvement of the antioxidant system and synthesis of compatible osmolytes. Shukla et al. (2017) documented the ability of *Ascophyllum nodosum* extract (ANE) to alleviate drought stress in soybean where they observed 50% higher relative content in the *Ascophyllum nodosum* extract treatment and reduced the degree of wilting of soybean grown under the influences of imposed drought conditions treated plants compare with control. Seaweed extract (SWE) of *Fucus spiralis* (macroalgae) was also found suitable in boosting *Salvia officinalis* growth and development under extreme water deficit (Mansori et al., 2019).

Treating drought stressed *Arabidopsis* plant with *Ascophyllum nodosum* extract reduces water lost by inducing concrete stomatal conductance control, maintaining the relative higher value of water use and mesophyll conductance during the last dehydration phase, prevent irreversible photosynthetic apparatus damages evoke pre-induced pathways for antioxidant defense system in combination with a more efficient energy dissipation mechanism were reported (Santaniello et al., 2017). Macronutrients content of leaf, growth and increase in resistance to drought was reported in grapes when treated with seaweed extract (Mancuso et al., 2006).

SEAWEED FOR PHYCOREMEDIATION

Toxic metals and organic pollutants are well-thought-out to be an obviously environmental challenge for animals and human health glob round. Due to urbanization, anthropogenic activities of different sources cause the increase in contamination of both terrestrial and aquatic by toxic metals and organic pollutants.

Phytoremediation involves the remediation of contaminants in a water body using algae (micro- and macroalgae). Fixation of CO_2 through photosynthesis and removal of extra nutrients effectively is achieved by algae at a minimal cost. It gets rid of pathogens and other toxic material from the water. Through the metabolic process, algae transform, accumulate, detoxify and/or convert into gasses (volatilization) xenobiotics such as heavy metals and other chemicals (Sunday et al., 2018).

It offers an advantage over conventional methods of remediation by its effectiveness, efficiency and eco-friendly nature (Sunday et al., 2018). Algae use the wastes as nutrients and enzymatically degrade the pollutants. Several algal features have qualified them model icons for the selective elimination and amassing of heavy metals which comprise great ability to tolerate exposure to heavy metals, competence to grow under both autotrophic and heterotrophic condition, the potentiality for genetic manipulation, phototaxy, phytochelatin expression,

and enormous surface area: volume ratios (Kaur *et al.*, 2019). The biosorption of HM ions by seaweed biomass may be achieved by different mechanisms such as complex formation, ion exchange, and electrostatic interaction (Mata *et al.*, 2008) being ion exchange the most important (Michalak & Chojnacka, 2010). Polysaccharides and proteins present in the algae cell walls provide the metal-binding sites (Gupta & Rastogi, 2008).

Mehta and Gaur (2005) coined out that binding capacity of a seaweed cell surface to a specific ion rest on several factors including chemical state of these sites, the coordination number of the metal ion to be sorbed, the number of functional groups in the algae matrix, the availability of binding groups for metal ions, ability to form the complex and strong affinity of the metal to the functional group (Table 2).

REMEDICATION OF HEAVY METAL

According to Abbas *et al.* (2014) marine algae eliminate directly heavy metals from water that is contaminated by two systematic approaches; first by a metabolic-dependent absorption into their cells at low concentrations, and the next by adsorption process. Seaweed cell wall polysaccharides and their derivatives and proteins make available the binding sites of metal. Algae have various chemical moieties on their surface such as hydroxyl, carboxyl, phosphate, and amide, which act as metal-binding sites (Igiri *et al.*, 2018) The sorption aptitude of a seaweed cell surface to a specific ion depends on more than a few factors such as the quantity of functional groups in the algal matrix, the number of coordination of the metallic ions to be sorbed, metal ions bioavailability, the ability of formation of complexes, to metal-to-functional group affinity and their chemical state (Ortiz-Calderon *et al.*, 2017). Living algal cells, bioaccumulation of heavy metal is achieved by two routes: the first is achieved by binding of potentially toxic elements to the cell surface; and the second phase is the transport of metal ions into cells actively (Flouty *et al.*, 2012). Algal cells in contaminated environment absorb heavy toxic metals which are translocated to the cell vacuole where they are accumulated. In this phase, binding proteins such as phytochelatin (PCs) and/or metallothioneins (MTs) bind to absorbed ions to prohibit toxic effects of accumulated metal ions in the host cell (Zeraatkar *et al.*, 2016). Polymeric substances secreted extracellularly have the potential of binding cations and stabilize and make them less harmful and non-bioavailable metals in the environment (Figure 5).

Table 2: Colour and cell wall components of three classes of seaweed

Division	Common name	Cell wall
<i>Chlorophyta</i>	Green algae	glucosides mannan, hydroxyproline, xylans, and Cellulose (β -1,4-glucoopyroside)
<i>Rhodophyta</i>	Red algae	Cellulose, xylans, several sulfated polysaccharides (galactans) calcification in some; alginate in Corallinaceae
<i>Phaeophyta</i>	Brown algae	Cellulose, alginic, acid, and sulfated, mucopolysaccharides (fucoidan)

Source: Ortiz-Calderon *et al.* (2017)

However, in the cells of non-living algal biomass, potentially toxic elements bind to the cell membrane surface. Hence, the process is known as an extracellular process (Godlewska-Żyłkiewicz, 2001). According to Zeraatkar *et al.* (2016) non-living algal biomass is more encouraging as compared to living algae because of the large metal ions sorption capacity at a significant rate, and it does not require growing nutrients in a medium. Non-living algal biomass could be considered as a conglomeration of large and complex chain of molecules (such as lipids sugars, pectins, cellulose, proteins glycoproteins, etc.) (Arief *et al.*, 2008) that act as adsorbents with binding affinity to heavy metal cations. Binding to heavy metals can be enhanced by either physical (drying, crushing, freezing, heating etc.) chemical treatment such as CaCl_2 , NaOH, HCl, formaldehyde, and glutaraldehyde (Bishnoi *et al.*, 2007). Physical treatments influence the important role of the cell wall in biosorption of metal ions, as non-living cell membrane destruction provides more surface area to increase the biosorption capacity and release the cell contents for possible increase in binding cell components to metal ions whereas chemical treatment promote ion exchange when treated with CaCl_2 as Ca binds to alginate (Bishnoi *et al.*, 2007) cross linkage of functional group is promoted by Formaldehyde and glutaraldehyde (Ebrahimi *et al.*, 2009), NaOH increase electrostatic interactions of metal ion cations while HCl dissolves polysaccharide, denature of the cell wall and improve biosorption (Rao *et al.*, 2005). It has been reported that seaweed absorbed heavy metal from the soil and water bodies (Table 4).

REMOVAL OF EXCESS NUTRIENT

Anthropogenic such as fertilizer application, insecticide, industrial waste amongst others yields excessive inorganic nutrients such as phosphorus and nitrogen leading to eutrophication in water body (Camargo & Alonso, 2006). Excessive non-metal nutrients from land to the body bodies is the principal water quality problem affecting the quality of coral reef health and loss of its communities which in turn cause a decrease in transparency of water and increase rate of fish mortality (Smith & Schindler, 2009; Amin *et al.*, 2018; Gasim

Table 3: Functional groups involve in biosorption of metals

Binding group	Structural formula	Ligand atom	Occurrence in selected biomolecules
Hydroxyl	-OH	O	PS, UA, SPS, AA
Phosphodiester	>P-O-OH	O	PL
Carboxyl	-C=O-OH	O	UA, AA
Amine	NH ₂	N	Cto, AA
Sulfonate	O-S=O	O	SPS
Thioether	-S<	S	AA
Secondary amine	>NH	N	Cto, PG, Peptide bond
Carbonyl (ketone)	C=O	O	Peptide bond
Amide	-C=ONH ₂	N	AA
Imine	=NH	N	AA
Imidazole	C-N-H	N	AA
Phosphonate	-OH-P-O-OH	O	PL
Sulfhydryl (thiol)	-SH	S	AA

PL= Phospholipids; LPS= LipoPS; PS= Polysaccharides; UA= Uronic acids; PG= Peptidoglycan; SPS= Sulfated PS; Cto= Chitosan; AA= Amino acids; TA= Teichoic acid. Adapted from Zeraatkar *et al.* (2016)

Table 4: Sea weed as phytoremediators of heavy metals

Seaweed	Toxic metal	Reference
<i>Ascophyllum nodosum</i>	Cobalt (Co)	(Kuyucak et al., 1998)
	Gold (Au)	(Kuyucak et al., 1998)
<i>Caulerpa racemosa</i>	Nickel (Ni)	(Holan, and Volesky, 1994)
	Lead (Pb)	
	Boron (B)	(Bursali et al., 2009)
<i>Fucus vesiculosus</i>	Nickel (Ni)	(Fourest and Volesky, 1997)
	Zinc (Zn)	(Volland et al., 2013)
<i>Micrasterias denticulata</i>	Cadmium (Cd)	(Volland et al., 2013)
<i>Laminaria japonica</i>	Zinc (Zn)	(Fourest & Volesky, 1997)
<i>Phormedium bohner</i>	Chromium (Cr)	(Dwivedi et al., 2010)
<i>Sargassum fluitans</i>	Copper (Cu)	(Davis et al., 2000)
<i>Platymonas subcordiformis</i>	Strontium (Sr)	(Mei et al., 2006)
<i>Sargassum filipendula</i>	Copper (Cu)	(Davis et al., 2000)
	Zinc (Zn)	(Fourest & Volesky, 1997)
<i>Spirogyra hyalina</i>	Iron (Fe)	(Figueira et al., 1997)
	Cobalt (Co), Mercury (Hg), Cadmium (Cd), Lead (Pb), and Arsenic (As)	(Kaewsarn & Yu, 2001)
	Lead Pb	(Gupta et al., 2013)
	Cadmium (Cd)	(Kaewsarn & Yu, 2001)
	Mercury (Hg)	(Bayramo et al., 2008)
<i>Microchaete tenera</i>	Lead Pb	(Gupta et al., 2013)
<i>Padina sp.</i>	Cadmium (Cd)	(Kaewsarn & Yu, 2001)
<i>Chlamydomonas reinhardtii</i>	Mercury (Hg)	(Bayramo et al., 2008)
<i>Durvillaea potatorum</i>	Cadmium (Cd)	(Deng et al., 2006)
<i>Ulva lactuca</i>	Cadmium (Cd)	(Lupea et al., 2012)
<i>Sargassum sp.</i>	Copper (Cu)	(Karthikeyan et al., 2007)
<i>Ulva fasciata</i>	Copper (Cu)	(Karthikeyan et al., 2007)
<i>Scenedesmus quadricauda</i>	Lead (Pb)	(Mirghaffari et al., 2017)
<i>Spirogyra sp.</i>	Chromium (Cr)	(Gupta et al., 2001)

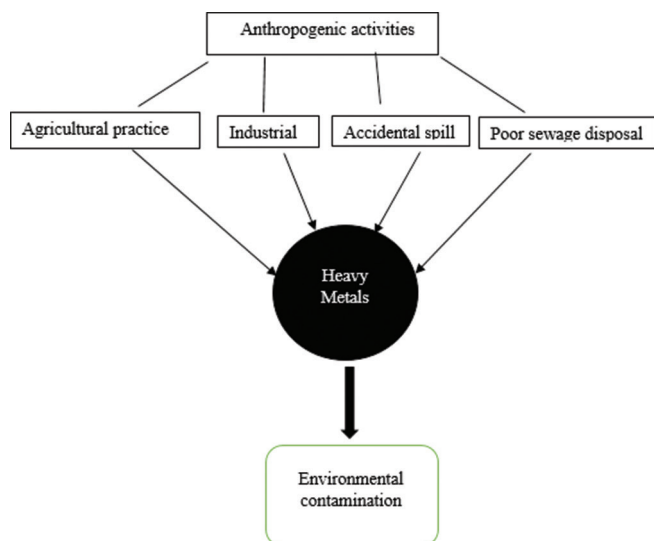


Figure 1: Schematic representation of heavy metals source by anthropogenic activities

et al., 2017; Ishak et al., 2018). Arumugam et al. (2018); He et al. (2008) documented the competency of seaweed in absorbing high nitrogen concentration and store in its tissue. Rathod et

al. (2014); Chen et al. (2008) proved the mechanism involved physisorption by active site at the surface of biosorbent and hold by a chemical bond (chemisorption) while intracellular transfer is achieved by active transport followed by biotransformation and intracellular accumulation.

CONCLUSION

Seaweeds are both agricultural and environmental tools for mitigating pollution, soil reclamation and improvement of agricultural productivity. They absorb, transform and bioaccumulate heavy metals and other non-heavy ones from the environment. Though researches have been previously reported, other species of algae need to be explored most especially dry biomass. Nevertheless, the need to explore tremendous applications of seaweed in these fields is still required.

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