Chapter 10
Seaweeds: Soil Health Boosters for Sustainable Agriculture

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Abstract Healthy soil is a key component to growing high quality crops, and it is essential that we manage our soils well. This would be majorly possible with intensive inputs of fertilizers, and irrigation as well as integrated soil management. Fertilization of soil with chemical-based inputs which has been practiced by farmers since several decades, has challenged the very existence of humankind. Intensive eco-friendly fertilization of soil is, therefore, a major challenge in face of synthetic fertilizers opening up the pandora box of environmental degradation and health hazards. Climate change, loss of biodiversity, and urbanization have also emerged as serious challenges to farmers. New innovations in fertilizer options for soil management need to be worked out. To lift agricultural productivity and food supply, fertilizer availability and affordability is prime concern of both farmers and stakeholders. Better still would be to adopt an integrated approach to soil management. It would not only address issues of environmental quality and land degradation but would potentially improve agricultural production and crop quality. Macro algae commonly referred to as seaweeds have fast emerged as promising candidates in soil management practices and "green" agriculture. Besides eliciting a growth-promoting effect on plants, seaweeds also affect the physical, chemical, and biological properties of soil which in turn influence plant growth. Seaweeds in fresh and dried form and seaweed concentrates enhance soil health by improving moisture-holding capacity and by promoting the growth of beneficial soil microbes, besides fertilizing it.

Seaweeds offer a wide spectrum agri inputs in the form of biofertilizers, soil conditioners, amendments, enhancers and biostimulants. Seaweeds are preferred because of the high amounts of macronutrients, micronutrients, vitamins, amino acids, and growth regulators, e.g., auxins, cytokinins, and gibberellins, they contain besides phycocolloids of great commercial value. Seaweed extracts are known to enhance seed germination, increase root and plant growth, yield, protein and quality, increase resistance to insects and diseases, resistance to drought and frost and increase shelf life. They are one of the best soil supplements which improve tilth and other properties of soil. Macro algal effectiveness is due to the fact that it fulfils

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the basic needs of both—the soil and the plants, and can efficiently alter the physical and chemical properties of soil. The potential of seaweeds as biofertilizers, biostimulants, soil conditioners, and soil additives for soil health is discussed in this chapter.

Keywords Seaweeds · Biostimulants · Soil supplements · Biochar · Mulch · Compost

10.1 Introduction

Over the last century global population has quadrupled. From 1.8 billion people around the globe in 1915, there is an increase to 7.3 billion people (UN report 2017) and in 2050, the population is expected to reach 9.7 billion (https://www.un.org/en/sections/issues-depth/population/). Accordingly, food demand is estimated to increase anywhere between 59% and 98% by 2050. Together with increase in consumption of animal products, this rise in population will drive up demand for crop species leading to pressures on agro industry. The constraints to increase crop production by various means would be transmitted to agricultural markets and farmers worldwide. Though theoretically, increasing the amount of agricultural land might appear a good option under such circumstances but practically land under agriculture would remain limited due to economic growth, urbanization, and rising affluence of developing economies. Hence, to meet the demands of about 10 billion people, enhancing productivity on existing agricultural lands would be a workable option. Nonetheless, approximately 50% of total habitable land which is under cultivation has to be "fit and healthy" in order to be productive.

Looking back in history, food demands have always remained high and new ways of farming have ensured food security from time to time. Chemical-based agricultural inputs became a popular practice in the early nineteenth century and synthetic fertilizers were frequently used to increase crop yield. Of late, however, intensive fertilization of soil with synthetic chemicals such as those with urea and potassium for crop management has resulted in significant environmental degradation. Besides environmental hazards viz., soil erosion, water contamination, pesticide poisoning, falling ground water table, water logging, and depletion of biodiversity due to overuse of chemicals (fertilizers, weedicides, and pesticides), health issues like cancer, premature ageing, abortions and many other ailments in humans are also on rise. The fallout of chemical-based agro industry has posed challenge to both, the long-run sustainability of agriculture and the survival of the farming community in developing countries.

Awareness among people on health issues and concern among environmentalists over deteriorating environment, has announced the transition of chemical-based agro industry into organic-based industry. Scientists are since long working out safe alternatives to chemicals and use of organic supplements such as green manure, vermicompost and foliar sprays along with AM fungi, nitrogen fixing bacteria is a common practice. Farming based on these inputs is considered a Good Agricultural Practice (GAP). Biofertilizers from microorganisms, such as bacteria, fungi, cyanobacteria, and macro algae and their metabolites (lipid extracted microalgal biomass residues or LMBRs) capable of enhancing soil fertility, soil health, crop growth, and/or yield, have emerged as a safe option to chemical fertilizers.

Micro algae or cyanobacteria, considered a boon for agro industry, are high value slow release organic fertilizers with established potency for soil conditioning (Metting et al.1990). They are popular amongst farmers especially for growing paddy (Tung and Shen 1985). Blue-green algae-algalization is reported as a safe agronomic practice. The ability of micro algae to produce copious amounts of mucilage that binds soil micelle, has made them popular soil conditioners. The ability of mucilage to absorb and retain water for a long time (Uysal et al. 2015), also greatly improves soil texture (Ibraheem 2007) besides stabilizing soil surfaces. Certain blue green algae (Cyanophyceae) remove sodium from saline sodic soils and increase soil fertility or reclaim damaged soil crusts.

Though micro algal biofertilizers have remained a sustainable option for long but of late micro algae are being tapped for biofuels, as phytoremediators and in maintaining ecosystem health. More so, the biggest limitation of micro algal agri inputs is the narrow range of crop species on which the effect is seen. As a result, agro industry is now flooded with algal products derived from macro algae or seaweeds.

10.2 What Are Seaweeds?

Algae, it is generally agreed, are simple plants that constitute a heterogenous assemblage of O_2-producing, photosynthetic, nonvascular organisms with unprotected reproductive structures. Regarded to be simple organisms, they are estimated to include from 30,000 to more than 1 million species (Guiry 2012). Today there is no particular classification scheme, and to both, phycologists and non-phycologists, algae are not a taxonomic category in the real sense of the term (Pereira and Neto 2014). Present molecular basis of classification which brings out inter relationships and closeness of origin between organisms, has excluded certain outlying subgroups from algae and has reserved the term for a central group naturally reconstituted within narrower limits.

In the present text, the author recognizes two major types of algae—the macro algae (commonly referred to as seaweeds) and micro algae (phytoplanktons) and in this chapter potential of the former group is unraveled as soil health boosters. Seaweeds occupy littoral zone, and are commonly referred to as greens, browns, and reds. These plants are found in all coastal areas of the world, in all climatic zones—from the warm tropics to the "icy polar regions." Generally speaking green seaweeds inhabit shallowest zones along the shore (upper intertidal), the browns are usually found in the mid-intertidal and sub-tidal zones and the reds inhabit the lower intertidal zone and deeper waters.

Seaweeds are major players in coastal ecosystems, and constitute the nutritional base for many shallow water food webs. They are architects of coastal marine meadows and underwater forests, provide homes and shelter for entire communities of associated fishes and invertebrates creating biological diversity niches. While culturing micro algae is simple and can be carried out in tanks, that of macro algae is done in the ocean and is commonly called “seaweed farming” or mariculture. It however, involves expert harvesting. Thus, obtaining large biomass of algae for farming does not require land and therefore, mariculture does not compete with crops for cultivable land.

The term seaweed was perhaps derived from the fact that several macro algae grew luxuriantly, became invasive and posed obstruction to navigation in sea and at ports. But if we exploit the invasiveness of seaweeds as feedstock for “agri inputs” and consider their ecological and economic importance, seaweeds are no longer just slimy stuff coating a seaside rock or fluttering in a tide pool but form a multibillion dollar industry (Kaur 1997). Seaweeds have dominated all spheres of our daily lives ranging from cosmeceuticals to nutraceuticals and pharmaceuticals; from fodder to food; from health supplements to esthetics and from ecological to agricultural spheres.

10.3 Seaweeds as Organic Fertilizers

Both types of algae have gained importance in organic farming and are rated as essential components of Good Agriculture Practices (GAP). When compared to micro algae, spectrum of macro algae appears to be broader, though no such claims have been made. The advent of synthetic fertilizers and chemical agri inputs took agro industry by storm but long-term adverse effects could not keep the promise of sustainable development. This practice emerged as one of the major causes of health risks from deadly diseases like cancer and have raised issues of environment safety as well. With organic farming picking up around the globe, seaweed resource has emerged a “safe” option. However, the combined costs of drying and transportation have confined its usage to limited places where the buyers are not too distant from the coast. The issues of overexploitation of the resource have also been raised and in several countries governments have executed plans to manage the resource while in others, regulations are still being worked out.

10.4 History of Seaweed as Agri Resource

According to Newton (1951), the earliest reference to seaweed manure is in the second half of the first century when the Roman Columella recommended that cabbages be transplanted at the sixth leaf stage and their roots be mulched and manured with seaweed. Since then methods for compressing seaweeds or marine plants into a compact, transportable form have appeared in literature. This is indicative of the value placed on seaweed manure and the need to transport the product over long distances. Since transportation of seaweed in wet form is uneconomical, alkaline seaweed extracts are becoming popular and the market has several such products for increasing the crop and soil health. The first attempt to produce a liquid extract was made almost a century ago (Penkala 1912). According to literature available, Dr. Reginald F. Milton, a biochemist while investigating fiber content of seaweeds worked out methods for liquefying kelp for use as a fertilizer. By 1947, he had succeeded in making a liquid product. His method, based on a hot pressurized alkaline process, was patented and has since then formed the basis for the Maxicrop process (Milton 1952) now a big name in liquid fertilizers. In the nineteenth century, coastal dwellers followed a common practice of collecting storm-cast seaweed, usually large brown seaweeds, and digging it into local soils. In the early twentieth century soil was fertilized with storm cast dried and milled macro algal material. Though in many places, the practice continued for centuries (Blunden and Gordon 1986; Metting et al. 1988; Temple and Bomke 1988) but with chemical fertilizers taking over, reports were only sporadic. However, since last decade or so seaweeds have regained global importance as eco-friendly inputs of organic farming and their use is being encouraged for sustainable crop production. Subsequent researches proved that while high fiber content of seaweed acts as a soil conditioner and assists moisture retention, the mineral content is a useful fertilizer and source of trace elements. This potential has made seaweeds farmer's first choice as soil health enhancer.

Interest in agricultural use of seaweeds is increasing rapidly as judged by the number of related publications appearing since 1950. Though the number of species with potential as fertilizer is small, the volumes of biomass they yield can be sizeable (Gibbs 1981). Studies in this field have revealed a wide range of beneficial effects of seaweed extract applications on plants, such as early seed germination and establishment, improved crop performance and yield, elevated resistance to biotic and abiotic stress, and enhanced postharvest shelf life of perishable products (Beckett and van Staden 1989; Hankins and Hockey 1990; Blunden 1991; Norrie and Keathley 2006).

10.5 Paradigm Shift: From Biofertilizers to Biostimulants

Seaweed extracts, concentrates, and suspensions in form of Seaweed Liquid Fertilizer (SLF) have wider use and market than seaweed mulch, seaweed meal or any other seaweed-based soil supplement. One big reason for popularity of SLF appears to be the nonavailability of the seaweed biomass in off-shore regions. The extracts are sold in concentrated form, are easy to transport and apply, and act more rapidly when given at lower concentration through aerial parts than through roots. The seaweed concentrates are applied to crops as root dips, soil drenches, soil conditioners, seed soak, or foliar sprays. Minerals and hormones in seaweed spray are absorbed through the epidermis of leaf and give resistance to numerous stresses such as frost, insect infestation, viral and fungal diseases. As the market is flooded with foliar sprays from seaweeds, one is forced to believe that extracts are more beneficial if used on aerial parts; however, it must be emphasized that the concentrates can also be used as drench and root dip which strengthen root system and healthy root system is a great binder of soil!

The seaweeds have been put to such use for centuries. Initially when researchers standardized methods, the extracts were accepted as liquid fertilizers and regarded as a tonic because of their medicine-like properties that enhanced plant growth. Subsequently, it was argued that since fertilizer had large amounts of nitrogen, phosphorus, and potassium, seaweed extracts be more correctly regarded as plant biostimulants.[1] Zhang and Schmidt (1997) from the Department of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University defined biostimulants as "materials that, in minute quantities, promote plant growth." By referring to biostimulants as substances or microorganisms applied to plants in "minute quantities," the authors distinguished biostimulants from nutrients. In general, biostimulants are accepted as materials, other than fertilizers, that promote plant growth when applied in low quantities.

In the revolutionized "pro organic" agro industry, demand is for broad-spectrum, organic products with dozens of nutrients as well as other benefits, and that is where biostimulants come in. Biostimulants are considered as a new generation of products for sustainable agriculture (Khan et al. 2009; Michalak et al. 2016). Biostimulants embrace the qualities possessed by the extract and therefore, the term biostimulant is generally equated with seaweed fertilizer. According to Yakhin et al. (2017) biostimulants are available in a variety of formulations and with varying ingredients but are generally classified into three major groups on the basis of their source and content. They are humic substances (HS), hormone-containing products (HCP), and amino acid-containing products (AACP). Among the biostimulants from various other sources, bioactive substances in the extract from seaweeds are the most studied. Seaweed liquid extracts which are processed from seaweed biomass using different manufacturing systems such as alkaline or acid hydrolysis or cellular disruption under pressure or fermentation, are now commercially available worldwide (Craigie 2011). They are extensively used as biostimulants by horticulturists, gardeners, farmers, and orchardists to enhance plant growth and fruit yields.

Ascophyllum nodosum (L.) is the most researched brown alga, and its extract has been commercialized as Acadian® for enhancing different plant growth attributes under normal and stress conditions. Kelpak® is another seaweed concentrate derived from a brown seaweed (*Ecklonia maxima*), and has been demonstrated to act as a biostimulant. A novel phlorotannin called Eckol has been isolated from Kelpak® which is found to have auxin-like activities, and its growth-promoting activity has been reported in a number of plants (Arafat Abdel Hamed Abdel Latef et al. 2017).

[1] A precise definition for biostimulants in agriculture has been proposed by the industry for consideration by the EU regulatory authority (Du Jardin 2015).

Stirk et al. (2014) reported brassinosteroids in the Kelpak™ seaweed extract. In addition to brassinosteroids, strigolactones have been found in the Seasol™ seaweed extract (from *Durvillaea potatorum* and *Ascophyllum nodosum*). The other popular products are Goemar GA 14, Seaspray, Seacrop 16, Algistim, Ujazyme and MAC.

In 1991, it was estimated that about 10,000 tons of wet seaweed were used to make 1000 tons of seaweed extracts with a value of US$ 5 million. However, the market has probably doubled in the last few decades and the global production estimate of seaweed biomass for soil and plant applications is well over 550,000 tons per annum (Nayar and Bott 2014).

Unlike, chemical fertilizers, extracts derived from seaweeds are biodegradable, nontoxic, nonpolluting, and nonhazardous to plants (Selvam and Sivakumar 2013, 2014) and contain nutrients that are essential for plant growth. In addition, seaweed extracts have many other molecules typical of plants, not yet characterized, but are thought to contribute to the efficacy of various liquid fertilizers. Bioinformatic studies have discovered plant genes that are activated when plants are treated with seaweed extracts (Nair et al. 2012; Jannin et al. 2013). There are also benefits from extracts that relate to improved soil structure, soil water holding capacity, and improved soil microbes.

10.6 What Makes Seaweeds a Promising Agri Resource?

Marine algae form an important component of the composting mixture and soil meal, where they contribute micro- and macroelements and chemical substances, e.g., amino acids, vitamins, plant growth hormones, and polysaccharides. The products are known to have fertilizer and/or protective role (Lacatusu et al. 2015), besides potential to improve the physical properties of soil, as amendments or supplements. They can be used in fresh, dried, powder, granular form and are also available commonly as Seaweed Liquid fertilizers. The special feature of seaweed fertilizers is the release of available nutrients into soil, which may last for several years (Eghball 2002). From among the three major types, it is the brown seaweeds—the Pheaophyceae or kelps which are preferred by the agro industry. Used directly as mulch, and “marinure,” fresh and in dry form or their extracts, composts, soil conditioners, kelps (a group of browns) are known to enhance plant growth and productivity (Eryas et al. 2008; Illera-Vives et al. 2013).

Species commonly used as source of nutrients for crops are *Fucus vesiculosus, Ascophyllum nodosum (algifert), Sargassum wightii, Padina pavonica, Turbinaria, Laminaria saccharina, Padina tetrastromatica*, and *S. tenerrimum* belonging to brown algae; *Hypnea musciformis, Champia,* and *Porphyra* belonging to red algae; and *Ulva lactuca* belonging to green algae (Fig. 10.1a–d).

It must be mentioned here that red algae are widely used in cosmetics and food industry while brown seaweeds are preferred over red and green in the agro industry. The brown seaweeds not only contain vitamins common to land plants, but also vitamins which may owe their origin to bacteria that attach themselves to sea plants (in particular Vit B12). Vitamin C is present in high proportion as Lucerne, while Vit

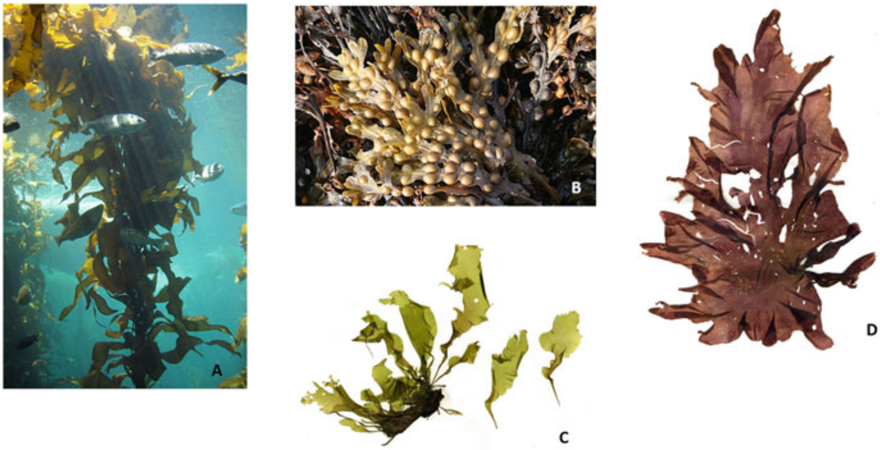

Fig. 10.1 Seaweeds commonly used as agri inputs. (**a**)—*Macrocystis*, (**b**)—*Fucus vesiculosus.* Both are brown algae commonly known as kelps. These are popular soil supplements. (**c**)—*Ulva* sp. a green seaweed, and (**d**)—*Porphyra,* a red seaweed. Among brown algae, *Ascophyllum*; in red, *Porphyra* and *Palmaria*, and in green seaweed species, *Ulva* has a high content of polysaccharides, up to 65% of dry weight. Green algae contain sulfuric acid polysaccharides, sulfated galactans and xylans; brown algae—alginic acid, fucoidan (sulphated fucose), laminarin (β-1, 3 glucan) and sargassan and red algae—agars, carrageenans, xylans, floridean starch (amylopectin like glucan), water-soluble sulfated galactan, as well as porphyran as mucopolysaccharides located in the intercellular spaces. Contents of both, total and species-specific polysaccharides, show seasonal variations and cold water species provide better quality phycocolloids when compared to seaweeds from warm waters

A is represented by its precursor beta carotene. B group vitamins present are B1, B2, B12 as well as pantothenic acid, folic acid, and folinic acid. Also found in the brown seaweed are Vit E, Vit K, and other PGRs besides indolyl acetic acid. Alginic acid and mannitol from brown algae are carbohydrates with chelating ability; they encircle and hold trace elements enabling plants to effectively absorb micronutrients that are generally in "unavailable" forms. These chelating agents not only make trace elements from seaweeds "available," they also make the trace elements more "available" to the plants. This may be due to the ability of soluble alginates where each metallic radical combines with one or more alginate molecules to form a polymer or large molecule with branched chains, thus leading to crumb structure in soil, an indicator of good water holding property of soil. Since alginic acid and mannitol do not immobilize available nitrogen as would cellulose, they decompose more readily than cellulose and contribute greatly to the formation of humus by stimulating microbial activity. As a result of catalytic action, alginic acid acts as a binder of soil particles and good soil texture results in a better soil aeration property with an accompanied increase in aerobic bacterial population. The aggregation of soil particles also increases the soil surface area which greatly facilitates chemical and biochemical exchange between elements thereby promoting increased productivity. According to Stephenson (1968), after the role of nutrients and trace elements, the alginic acid in brown seaweeds is important as it confers seaweed with soil conditioning properties.

In general seaweeds can contribute to the plant and soil health through four ways: (1) nutritional benefits (nitrogen, phosphorous, potassium, trace elements), (2) disease resistance (sulphated polysaccharides), (3) endocrine effects (cytokinins, auxins, gibberellins), and (4) soil conditioning (water holding capacity, beneficial soil biota) (Winberg et al. 2011).

10.7 Tapping Drift and Invasive Seaweeds: As Soil Amendments

Waste algae—the drifts and the casted seaweeds are composted and directly applied as soil conditioners and/or fertilizers in many coastal regions of the world (Castlehouse et al. 2003). The biomass is subjected to different composting technologies and is stabilized. The obtained compost quality varies with the feedstocks that have been used to produce it, the methods applied for pretreatment of biomass before composting, the composting time, and the method used to process the compost (Vendrame and Moore 2005). Seaweed compost treated as organic fertilizer has several advantages over regular plant compost, especially in the content of micro- (Mn, Zn, I) and macroelements (P, K, Ca, Mg), as well as the content of plant hormones such as total auxins and cytokinins (adenine) (~5 times more) and total amino acids (~7 times more) it contains (Abou El-Yazied et al. 2012).

10.7.1 Drift Seaweeds

Since a large biomass of dry seaweeds is required for application in fields as soil amendments, it would mean harvesting tons of wet algal biomass and ultimately disappearance of species. This limitation can be overcome if we exploit drift and invasive seaweeds as soil amendments, and which are otherwise a nuisance on seacoasts (drift plants). The large biomass invites bugs and emanates unpleasant smell, and may also pose problems in navigation (invasive plants).

Drift seaweed is known to accumulate in lines left behind by the receding tide. As the height of the high tide recedes during the spring–neap cycle (which happens twice a month) successive lines are left behind. Such drifts are seen in exposed coasts where drift lines are made generally of brown seaweeds (Fig. 10.2a–c). In more sheltered localities, however, green algae may be more prevalent. In certain regions like south coast of England, huge amounts of such material accumulate, often necessitating removal, else rotting of biomass leads smell bad.

Fig. 10.2 Drift seaweeds provide a large biomass which is processed as fertilizer. (**a**)—Giant kelp, (**b**)—*Sargassum muticum* thrown on the beach is frequently collected and used to amend soil. By Graça Gaspar—uploaded with the author's permission, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid (**c**)—Strandlines formed by the beach-cast seaweed

The drift seaweed in olden days was occasionally dumped inland without any treatment, constituting a new source of pollution. But gradually people became aware of the potential of this biomass and experimented with it as soil amendment where the detached and broken seaweed thalli were used to fertilize soil. In one such example, in Aran Islands off the west coast of Ireland, the drift seaweed along with shore sand was transferred to bare limestone to make "buaile" or small pastures. Of late, such practices have become popular as eco-friendly and sustainable options. Nowadays part of this algal mass is composted and then used for growing crops and vegetables in various types of "seaweed amended" soils. In several parts of the world, drift seaweed or beach-washed seaweed is collected and dried for use (McHugh 2003; Michalak and Chojnacka 2013; Cole et al. 2016) while the leftover biomass portion is designated for the landfill disposal. In many places like Breton, farmers transport large quantities of a brown seaweed, *Himanthalia elongata* for raising the artichoke crops (The seaweed site: information on algae). In Cornwall (United Kingdom), the practice is to mix seaweed with sand, then allow it to rot and later dig it in soil. This checks the unpleasant sight of bugs and smell emanating due to decomposition of the biomass. Detached seaweeds sometimes called "total drift" have been used to raise crops like potato. In Brittany (France), for over a few hundred kilometers of the coast line around the beach-cast, brown seaweed is regularly collected by farmers and used on fields. In Scotland farmers use

Ascophyllum which after composting is obtained as a dried powder. Similar practices are carried out in countries with a vast coastline and more tropical climate like the Philippines, where not only large quantities of *Sargassum* have been collected, used wet locally, but sun-dried biomass is also transported to other areas. "Afrikelp" is another example of a commercially available dried seaweed sold as a fertilizer and soil conditioner. It is produced from brown seaweed *Ecklonia maxima* that is washed up on the beaches of west coast of Africa and Namibia. In Puerto Madryn (Argentina), large quantities, about 8000 tons of green seaweeds are cast ashore every summer which interfere with recreational uses of beaches besides unpleasantly rotting in situ (Eyras and Rostagno 1995). In all the cases, addition of compost is reported to result in improving water holding capacity and plant growth. Such practice is being encouraged elsewhere also where drift seaweed provides compost, thus reducing problems of environmental pollution.

Processing of drifted biomass is easily carried out by mixing with a lignocellulosic substratum (80:20 seaweed: sawdust proportion, in dry weight, DW). There are evidences that *Ascophyllum* drying under controlled conditions for 11–12 days, results in breaking of alginate chains into smaller chains which retain the property of forming gels with calcium but are weaker. The composted product is dark brown, granular with 20–25% water and can be easily stored and used in this form. The product has yielded good results in areas with steep slopes which are difficult to cultivate with conventional equipment and are likely to suffer soil loss by runoff. Spraying such slopes with composted *Ascophyllum*, clay, fertilizer, seed, mulch, and water has given good results, even on bare rock. The spray is thixotropic, i.e., it is fluid when a force is applied to spread it but it sets to a weak gel when standing for a time and sticks to the sloping surface.

Since algal biomass has become a popular soil supplement, different composting technologies are applied for algal biomass stabilization. They may be divided into three groups: (1) passive piles or windrows—A method in which material is left undisturbed, relies on natural convective air flows for aeration; (2) turned or aerated piles or windrows—Here, the air is provided by mechanically turning and mixing the material; and (3) in-vessel systems—optimum environmental conditions of aeration, moisture, and temperature for the quick decomposition of algal biomass are maintained (Michalak and Chojnacka 2013).

Besides drift seaweed, "mid-beach" plants can also be gathered. These are often found scattered on the beach from the water's edge to the highest point of recent high tides. The seaweed "mid-beach" is drier than seaweed at the tide line and therefore lighter to carry. It also has fewer bugs than the seaweed high up on the beach, making it a little more pleasant to gather. For a sustainable approach, fine broken up seaweed patches smaller than leaf size are collected and are applied as mulch. To get best results, seaweed mulch is normally not used on heavy soils but is preferred as a surface dressing on light sandy soils. This is because seaweeds have some insoluble fibers in their cell wall and if the alga is dug into such soils, the fibers form an impermeable layer. However, in light soils, the seaweed (kelp) biomass provides nutrients and other growth promoting substances.

Co-composting of drifting and beach-cast seaweeds is recommended for utilization of the waste biomass (Illera-Vives et al. 2013). If care is taken to avoid mixing of treated straw or urban and industrial sludge in the compost as co-composting materials, the produced seaweed compost is not only of good quality but is also with very low content of pesticides, such as organochlorine compounds and cereal growth regulators (Morand 1990).

10.7.2 Invasive Seaweeds

Some seaweed species like *Sargassum muticum, Undaria pinnatifida, Caulerpa taxifolia*, and *Enteromorpha* have invaded ecosystems along the coasts of many countries displacing native algae and seagrasses, reducing biodiversity and impairing habitats of fish and invertebrates. Eradicating these invasive species has so far not only been a costly affair but has also met with little success as the biomass is huge. Recently such invasive seaweeds have been used for high value products like biofuel and antioxidants. If biomass of such species is also exploited for fertilizing soil, it could help in making the "undesirable" bioresource available and more so make its removal from the site justified. This would cater to the market demand for biomass. A few reports from various countries on use of invasive seaweeds as agricultural inputs have appeared indicating the huge potential of such biomass in agriculture. *Gracilaria salicornia*, a common invasive red algal species found in Kāne'ohe Bay and around the world, is a potential potassium fertilizer source. Analysis of invasive brown algae, *Turbinaria ornata* and *Sargassum mangarevense* indicate them to be rich in potassium, nitrates, calcium, iron, and polyunsaturated amino acids, with a very low level of any heavy metals (Zubia et al. 2003). In another study, soils amended with *Eucheuma* spp. (invasive) used to raise sweet potato resulted in better plant growth when compared to the control (https://scholarspace.manoa.hawaii.edu/handle/10125/101058) while *Enteromorpha* used in China has increased crop yield in several cases. Realizing their importance, commercial products from invasive seaweeds have appeared in the market, e.g., *NZBioActive*, a biostimulant is extracted exclusively from brown alga *Undaria pinnatifida,* an invasive seaweed.

However, the entire process has limitations of the type—high costs incurred in processing and transporting biomass to the fields especially if it is to be sent to off-shore sites. Moreover, the drift algal biomass invites bugs besides consuming area suitable otherwise for waste settlement, and issues related to leachate and biogas production during decomposition of algae (Vallini et al. 1993).

10.8 The New Biomass Service: Biochar

Seaweed biomass besides liquid fertilizer or manure also offers a feedstock for the production of nutrient-rich biochar which can be used as soil ameliorant. The product is obtained from intensely cultivated seaweeds such as *Saccharina*, *Undaria*, and *Sargassum*—brown seaweeds, and *Gracillaria*, *Kappaphycus* and *Euchema*—red seaweeds. These products have introduced the concept of fertigation in raising kitchen gardens and on commercial farms (Fig. 10.3a–g).

Biochar, a C-rich "biological charcoal," is a solid material obtained by pyrolysis which is the decomposition of organic material under oxygen-limited conditions and at a temperature ranging from 350 °C to 900 °C (http://www.biochar-international.org/). When compared to raw biomass, biochar contains a higher amount of carbon (C) when compared to cow-derived manure, besides other elements such as hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). Biochar is known for its high stability and surface properties, such as large surface area, porous structure, and surface functional groups, though the properties may show variations based on the source of raw material (i.e., biomass), and production conditions (Roberts et al. 2015).

Fig. 10.3 Various forms of seaweed fertilizers. (**a**)—The dried form can be added to soil to improve tilth while (**b**)—the crushed granular form can be added as supplement. The dried seaweed is packed (**c**) and sent to factories where liquid fertilizers are prepared (**d**). Biochar is the new product (**e**) where seaweed is occasionally mixed with pine wood to render a balanced fertilizer. For large-scale farming, the plants are fertilized and irrigated (fertigation) with one application (**f**, **g**). Source: wikivisually and creative commons

Biochar is used as soil amendment and fertilizer (Bird et al. 2011); as a reducer of greenhouse gas emissions; as adsorbent of wide range of pollutants in the air, soil, and water; and as an energy source, among other applications. Application of biochar to the soil allows fixing carbon, improving soil quality by neutralizing acidic soil, promoting cationic exchange capacity, and increasing the activities of microorganisms. When biochar is applied, the basic cations of biochar are discharged into the soil, with aluminum (Al) and H^+ being replaced. As a consequence, the cationic exchange capacity of the soil increases (Chan et al. 2007). In addition, biochar has high N, phosphorus (P), calcium (Ca), and potassium (K) concentrations, which directly provide nutrients to the soil or associated microorganisms.

While there is some variability in biochar properties as a function of origin of seaweed, there are several defining and consistent characteristics of seaweed biochar. In particular a relatively low C content and surface area but high yield, essential trace elements (N, P, and K) and exchangeable cations (particularly K) define biochar. The pH range of biochar is from neutral (7) to alkaline (11), making it work for broad-spectrum applications in diverse soil types. Blending of seaweed biochar with rice husk and pine saw dust is known to act as a value-added soil ameliorant that combines a high fixed C content with a mineral-rich substrate to enhance crop productivity.

10.9 Limitations

Interest in seaweeds as "safe" or eco-friendly fertilizers has increased over the years. The most intriguing feature of this resource is the availability of biomass which when wet appears bulky but the dried form produced is quiet less. To date, seaweeds only produce a small fraction of the global supply of biomass with below 30×106 fresh weight (FW) tons of seaweed, in comparison to 16×1011 tons of terrestrial crops, grasses, and forests. The problem gets compounded when the effect of climate change on the growth of seaweeds is considered. The seaweed biomass, which is known to have multiple benefits, contains vitamins that get decomposed when the biomass is exposed to intense heat outside the sea. For using the dry biomass therefore, one important step would be quick harvest and efficient drying process. This would also be applicable to drift seaweeds which need to be removed quickly from coast and processed for use. The second limitation is the amount of biomass required for compost or mulch is too high and if seaweeds are harvested unmindfully, environmental concerns are bound to be raised. It is therefore, recommended that only species that can be cultivated through mariculture be used. If at all harvesting from sea is required, it should be done under strict surveillance. The harsh reality is that if the waters are polluted especially with oil spilling and nuclear run off, the biomass becomes unfit for use as it gets contaminated with toxins including heavy metals. According to Smith et al. (2010), algae can contain high levels of organic arsenic, which could be toxic if mineralized. Large amounts of cadmium have also been measured in different kinds of seaweeds (Besada et al.

2009). However, Verkleij (1992) stated that only in heavily and chronically polluted waters, problems are to be expected regarding seaweed quality (for consumption and agri input). As long as seaweeds are collected in clean areas, no toxicity is expected, but still monitoring water quality would be necessary when large areas of seaweeds are harvested for soil fertilization purposes.

The other constituents in biomass, like polysaccharides especially alginic acid are known to undergo seasonal variation and may be extremely low at some point in life cycle of the seaweed. Harvesting plants during such stages would yield a poor-quality soil amendment. Hence, basic knowledge of the life cycle of these plants is necessary before they are harvested, discouraging collection of poor-quality biomass and wasting it in the process. The economics of the technology is also lopsided—The seaweed decomposition in most cases is slow and transporting wet biomass inland becomes not only costly but also wasteful if the plants start to rot. This would mean that the resource is more available to coastlands while basic agriculture is carried out in inland areas. Similarly, the drift seaweed biomass needs to be cleared from the site before it gets infested with flies. Awareness among local populations about importance of seaweeds is required. Local population should be educated that howsoever abundant and vast seaweeds may appear in sea, they are not quick to replenish especially the seaweeds that produce maerl. They have to be harvested scientifically and crude methods would be damaging to the resource.

For agri industry to derive maximum benefits from seaweeds, a major research effort is needed to elucidate the complex modes of action and forms of seaweed applications on diverse crops. Each plant has special requirements which are generally not met with by soil unless it is amended. Overdose of seaweed fertilizers/biochar/manure may result in inhibitory effect and the results may not be convincing. In addition, we need to recognize that seaweed extracts are inherently different since their source and processing is different which confers them with specific stability properties (Stirk et al. 2014). Furthermore, their capacity to elicit plant responses also depends in part upon the application usage rates, application frequency and the timing of applications in relation to plant development life cycle. For best results seaweed products can be applied in combination with other organic products. Therefore, we need to standardize methods for determining the appropriate time and plant stages where the results would be encouraging in terms of crop yield. We also need to define the optimal dosages required to maximize the yield besides working out combinations to obtain a value-added product. Some soils may also have special requirements where amendment has to be worked out for specifications. For example, in dry areas or in areas with poor water retention quality of soil, adding seaweed in mulch form or granular form is effective in improving water retention of soil but it may also increase the salt content of soil. It is therefore, important that soil testing is carried out. In several cases, the soil becomes “hot” upon amending with solid form of seaweed and seedlings get “burnt.” Whole seaweeds or seaweed meals are reported to inhibit seed germination and plant growth, to reduce N availability on the short term and possibly to release toxic sulfhydryl compounds (Craigie 2011). In such cases, extracts from seaweed are recommended.

Putatively, seaweed biomass may be a useful amendment for crop production due to provision of primary plant nutrients and micronutrients (e.g., N, P, K, Ca), effects on soil water holding capacity, and promotion of microbial activity, among other plant production benefits, but may be limited by high sulfur, salt, and heavy metal content. The amount of literature on detrimental effects of seaweed application to crops is relatively scarce compared to the beneficial effects; these detrimental effects disappear after a few weeks. The biggest limitation is that the seaweed agri products are slow to show results. The bottom line, however, is that in the long run these would prove healthy, economical, and beneficial—only we need to be patient with results.

10.10 Conservation

Popularity of seaweed agri inputs has put pressures on marine resources and overharvesting in several instances, has resulted in dwindling biomass and disappearance of a few species while others face dangers of extinction. It is possible that overexploitation of natural seaweed resources leads to significant ecological, economic, and social consequences at local, regional, and even global scales (Graham et al. 2007; Rebours and Karlsen 2007). This has forced local governments to develop stringent regulations and directives for sustainable exploitation of seaweed resources. In many regions seaweed harvesting is under stringent regulation by the local governments. Countries like Chile, Norway, Portugal, and Canada have developed and implemented coastal management plans including well-established and sustainable exploitation of their natural seaweed resources (Rebours et al. 2014). The State of Hawaii prohibits collection of *Gracilaria* with "bumps" on it. These bumps are reproductive bodies on the female plants, that allow the plants to multiply themselves if left in the water.

Resource scientists, managers, conservationists, governments, and other stakeholders need to be proactive in the sustainable management of these valuable resources. Each country is, however, in need of long-term and ecosystem-based management plans to ensure that exploitation is sustainable.

Besides making rules for seaweed harvesting, "seaweed farming" needs to be carried out on mass scale for biomass availability, raw material for agri products (McHugh 2002). The seaweed aquaculture industry still requires technological and management improvements, institutional changes, and appropriate environmental and social frameworks, especially in developing countries which have vast resources but less of know-how in this field (Valenti 2008; Oliveira 2009; Abreu et al. 2011; Marroni and Asmus 2013).

10.11 Concluding Remarks

The seaweed agri products have since long been cited as promising soil amendments and fertilizers. A large variety of products are available in market, but little do we realize that a large biomass is harvested to bring these products to the market. If harvesting of seaweeds is carried out unmindfully, most seaweed resources will get depleted. The solutions lie in improving the strains and mass cultivation of commercial species. With climate change adversely affecting the crop yield, it is important that integrated methods of agriculture are adopted. Seaweed resources can be used in several combinations and in forms that do not require much expertise. They enhance the effect of other forms of manure when used in combinations. Though biotechnology has provided us with better quality GM crops, but some genetically engineered products such as brinjal have generated controversies, focus is therefore, on natural means of increasing crop yield. The first step in such an endeavor is to improve soil health. Seaweeds if used judiciously have a great deal to offer. It may be interpreted as role reversal—from our dining table as food they have moved to fields as food providers! To derive maximum benefit from seaweeds, limitations of the usage must be worked out.

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