Introduction

Seaweeds form one of the important marine bioresources and could be termed as the futuristically promising plants. Being a group of unique structure and biochemical composition, seaweeds could be exploited for their multi-functional properties in the form of food, energy, medicine and cosmetics (Table 1). Although, seaweeds in India are used for industrial production of agar and alginate and as a fertilizer, they are yet to be utilized on a large scale for various purposes, which is not being done, due to lack of their awareness among the Indian populace. In order to harness the rich potential of seaweeds in India, it is essential to extend their use and areas of application.

India has a long coastline of about 6500 km with diversified habitats harbouring numerous flora and fauna. Seaweeds and sea plants make up an integral part of the coastal ecology and landscape. Seaweeds occur along the coastline with a definite zonation. Upper littoral zone consists by strong thalloid members species. Mid-littoral zone is dominant of both Chlorophyceae and Pheophyceae algae while lower littoral is representative of delicate species mainly of Rhodophyceae. (NIO, report, 1975)

For centuries, agricultural areas close to these coastal zones have utilized seaweeds as a valuable source of organic matter for various soil types and for many different fruit and vegetable crops. Fertilizers derived from seaweeds *(Fucus, Laminaria, Ascophyllum, Sargassum* etc.) are biodegradable, non-toxic, non-polluting and non-hazardous to human, animals and birds (Blunden ,1991). Seaweed manure besides increasing the soil fertility increases moisture holding capacity and supplies adequate trace metals thereby improving the soil structure. An adequate amount of potassium, nitrogen, growth promoting hormones, micronutrients, humic acids etc. are present in seaweeds.

In addition to seaweed fertilizers nontraditional products such as humates and fish emulsions have received tremendous attention in recent years. Although the nutrient content of these products is as varied as the sources from which they are derived, alternative products can be used to furnish primary and secondary nutrients, improve soil cation exchange capacity, increase the presence of plant growth hormones, and stimulate plant defense mechanisms against diseases and insects. In short, seaweed extracts and traditional and nontraditional products serve to complement each other and can furnish a wide variety of chemical, physical and biological improvements to the crop and its growing environment. (www.acornorganic.org)

Use of seaweeds and seaweed extracts in agricultural programs has improved overall yields and quality of fruit/vegetable in a variety of crops. Of course, seaweed extracts are not stand-alone fertilizer products and should be used within regular crop management programs to be most effective.

One of the most common uses of sea-based products is as foliar fertilizers. Foliar fertilization is the application, via spraying, of nutrients to leaves and stems where they are absorbed into the plant (Alexander, 1985). Organic growers may use sea-based foliar fertilizers to supplement their soil fertilizers, either by spraying bi-weekly throughout the growing season or by spraying one-time midseason as a nutrient boost. The nutrients are not leached down in to the soil but are available to the plant through leaf openings such as lenticels, hydathods and stomata. Leaves absorb nutrients within 10 to 15 minutes of its application. Foliar application, therefore, is often the most successful when used to supply an element that is lacking in the plant (Boynton, 1954). Seaweed contains a number of micronutrients in small quantities including Mg, S, Fe, Mn, Zn, B, Cl and Na. Plants deficient in these trace elements could respond noticeably even when only small amounts are added. Researchers have also found that seaweeds also contain a number of plant growth hormones, including cytokinins, gibberellins, abscisic acid, indole acetic acid and phenolic compounds (Verkleif, 1992).

Seaweed extracts have been proven to accelerate the health and growth of plants. Seaweed stimulates beneficial soil microbial activity, particularly in the pockets of soil around the feeder roots which results in a substantially larger root mass. This root mass, or "rhizosphere" is the place where mycorrhizae make their home. One benefit of increased rhizosphere activity is to improve a plant's ability to form healthier, stronger roots. Another is to enhance the plant's own natural ability to ward off disease and pests. For example, it has been observed that aphids and other types of sap feeding insects generally avoid plants treated with seaweed. Yet another benefit is to make more soil nutrients available to the plant. The rhizosphere forms a nutrient food bank for the plant, from which it is able to draw on in times of stress. Finally, due to the increased mass and depth of the roots from seaweed's influence, the plant is better able to absorb moisture and nutrients from the soil. (www.ghorganic.com)

Many brands of seaweed liquid fertilizers like Maxicrop (UK), Kelpak 66 (South Africa), Seagrow (New Zealand), Algifert (Norway), Plantozyme, Shaktizyme (India) etc. are available in the market. The diluted extract when sprayed on plants, shows beneficial results in terms of health of plants, increase in rate of growth, resistance to pests, and higher yield. The concept of spraying fertilizer on plants is gaining importance and many firms in India are coming forward to prepare seaweed bio-fertilizers. Technical know-how on seaweed bio-fertilizer is available with National Institute of Oceanography, Goa, Central Salt & Marine Chemical Research Institute, Bhavnagar, Gujarat and other industries working on seaweeds for commercialization.

An extensive survey of Indian marine algae has been made by Krishnmurthy and Joshi, (1970). In recent years, a few workers have attempted to evaluate resource potentials of the Indian coast (Untawale and Dhargalkar, 1975 and Subba Rao, 2007). A check list of 624 species has been prepared for Indian sub continent by Untawale *et al.* (1983)

Algal vegetation is usually luxuriant from October to February, along western coast of Maharashtra. In summer months i.e. March- April onwards it is almost negligible. Certain species like *Porphyra*, *Bangia* grow luxuriently only during the monsoon. Most of the other species start germination and growth from October onwards. Some species like *Ulva, Enteromorpha, Gelidium* occur throughout the year.

Table 1. Some of the common uses of seaweed species.

Sr. No	Species	Food	Feed	Industrial uses	Medicine	Fertilizer
Class Chlorophyceae (Green algae)						
1.	*Ulva fasciata*	+	+	-	+	+
2.	*Enteromorpha compressa*	+	+	-	+	-
3.	*Monostroma oxyspermum*	+	+	-	-	-
4.	*Cladophora fascicularis*	+	+	-	-	-
5.	*Chaetomorpha media*	+	+	-	-	+
6.	*Codium fragile*	+	+	-	-	-
7.	*Caulerpa sertularioides*	+	+	-	-	-
Class Pheophyceae (Brown algae)						
8.	*Dictyota dichotoma*	+	-	+	-	-
9.	*Spatoglossum asperum*	-	-	+	-	+
10.	*Hydroclathrus clathratus*	-	-	+	-	+
11.	*Stoechospermum marginatum*	-	-	+	-	+
12.	*Colpomenia sinuosa*	-	-	+	-	+
13.	*Dictyopteris australis*	-	-	+	-	+
14.	*Padina tetrastromatica*	-	-	+	-	+
15.	*Sargassum cinerèum*	-	+	+	+	+
16.	*Sargassum ilicifolium*	-	-	+	+	+
17.	*Laminaria digita*	-	-	+	+	+
18.	*Macrocystis pyrifera*	-	+	+	+	-
Class Rhodophyceae (Red algae)						
19.	*Porphyra vietnamensis*	+	-	-	-	-
20.	*Amphiroa fragilissima*	+	-	-	-	-
21.	*Jania adhaerens*	-	+	-	+	-
22.	*Gracillaria corticata*	+	+	+	-	-
23.	*Hypnea musciformis*	+	-	+	-	-
24.	*Centroceros clavulatum*	+	+	+	-	+
25.	*Laurencia papillosa*	+	-	+	-	-
26.	*Chondrus crispus*	+	+	+	-	-
27.	*Eucheuma uncinatum*	+	-	+	-	-
28.	*Gelidiella acerosa*	-	-	+	-	-

+ indicates application and - indicates absence/ no report of use (Chapman& Chapman1980)

Scope of present investigation

Sindhudurg and Malvan regions along the west coast of Maharashtra support a rich growth of seaweeds. Seaweed species such as *Sargassum, Padina, Ulva, Caularpa, Hypnia, Gracillaria* etc. growth luxuriantly on the rocky substratum found in this region. These algal species are used as feed to some extent by coastal population however they are hardly used for consumption as food along Indian coastal areas. Naturally dried seaweed mass functions as a manure and adds nutrients to the saline soil in this area which helps to improve its organic matter content and fertility. A great deal of systematic work regarding the application of seaweed manure and fertilizers and their influence on the physiology of crops is lacking. Impact of seaweed application on germination and growth has been reported in a few studies. But biochemical investigations of seaweed treated plants are very rarely attempted.

The concentration of fertilizers, time and method of application, stage of crop growth etc. aspects of seaweed manuring. The data available on these aspects is insufficient. Present work is undertaken to add into the existing knowledge regarding the application of seaweed manures to crop plants. Effect of liquid extract of seaweed on germination, growth and physiology of fenugreek has been studied. Fenugreek is a leafy vegetable grown popularly in all the region of India. Liquid concentrates of three seaweeds viz. *Ulva, Sargassum* and *Gracillaria* employed in this study were prepared by crushing, boiling and soaking the seaweeds. A range of these seaweed concentrates was applied to fenugreek seeds to observe the effect on germination. From this pilot study a few concentration were selected for further analytical work wherein effect of SWC on biochemical parameters was studied. For comparison, Hoagland nutrition medium was considered and plants grown in this nutrient medium were compared with those treated with SWC.

The dissertation is divided into distinct chapters. A brief idea about the nature of work carried out and its scope is given in the beginning as '**Introduction**' which forms the first chapter. A precise survey of literature and books and other documents is compiled in the second chapter of '**Review of literature**'. All the standard methodology used for different physiological analytical and other work is described in the third chapter of '**Materials and Methods**'. Observations reported in the study are discussed, with the help of relevant literature and documents in the fourth chapter i.e. '**Results and Discussion**'. Fifth chapters includes a comprehensive '**Summary and conclusion**' of the entire work. A variety of research Journals, books, review, articles, dissertations and also web sites were refereed to make the present study up to date. These are collectively documented at the last in '**Bibliography**'.

Chapter I

Review of Literature

A. Applications of seaweeds

1. Food

For several centuries there has been a traditional use of seaweeds as food in China, Japan and the Republic of Korea. As people from these countries have migrated around the world, this custom has moved with them, so that today there are many more countries where the consumption of seaweed is not unusual.

In some developing countries there has been a tradition of using fresh seaweeds as vegetables and in salads. China is the largest producer of edible seaweeds. The greater part of this is for kombu, a brown seaweed, *Laminaria japonica*, that is grown on suspended ropes in the ocean.

The most widely known seaweed used for food is *Porphyra* and known as Nori in Japan. It is classified as the red alga, which has red to purple pigments. Nori is used to wrap sushi and for making numerous snacks. The other common food item is the low cost but highly nutritious kelp known as Kombu usually sold in 5-6-inch dried pieces and can be found in health food stores. It is available in different forms as boiled, soya sauce flavored kombu, lightly pickled kombu, and powdered kombu that can be sprinkled on food or used in drinks. A third seaweed widely used in Japan is *Undaria pinnatifida*.

From Nutritional point of view, edible seaweeds are low-calorie foods, with a high concentration of minerals, vitamins and proteins, and a low content of lipids. Quality of protein and lipid in seaweeds is comparable to other diet vegetables mainly due to their high content of essential amino acids and unsaturated fatty acids. Dietary fiber content ranges from 33% to 75% of dry weight, and mainly consists of soluble polysaccharides (about 17% to 59%). Fibers differ chemically and physico-chemically from those of land plants and thus may induce different physiological effects. Marine algal dietary fiber may show important functional activities, such as antioxidant, antimutagenic and anticoagulant effect, antitumor activity, and an important role in the modification of lipid metabolism in human body.

Seaweeds have a high nutritional value, therefore an increase in their consumption, would suffice increased food requirement to some extent (Jimenez & Goni, 1999). Seaweed has such a large proportion of iodine compared to dietary minimum requirements, that it is primarily known as a source of this nutrient. The highest iodine content is found in brown algae.

2. Animal feed

For a long time, animals such as sheep, cattle and horses that lived in coastal areas have eaten seaweed, especially in those European countries where large brown seaweeds were washed ashore. Today the availability of seaweed for animals has been increased with the production of seaweed meal i.e. dried seaweed that has been milled to a fine powder. Norway was among the early producers of seaweed meal, using *Ascophyllum nodosum*, a seaweed that grows in the eulittoral zone so that it can be cut and collected when exposed at low tide. France has used *Laminaria digitata*, Iceland both *Ascophyllum* and

Laminaria species, and the United Kingdom, *Ascophyllum.* Because Ascophyllum is so accessible, it is the main raw material for seaweed meal and most experimental work to measure the effectiveness of seaweed meal has been done on this seaweed.

Analysis of these products shows that it contains useful minerals (potassium, phosphorus, magnesium, calcium, sodium, chlorine and sulphur), trace elements and vitamins. Trace elements are essential elements needed by humans and other mammals in smaller quantities than iron and include zinc, cobalt, chromium, molybdenum, nickel, tin, vanadium, fluorine and iodine. Because most of the carbohydrates and proteins are not digestible, the nutritional value of seaweed has traditionally been assumed to be in its contribution of minerals, trace elements and vitamins to the diet of animals.

Ascophyllum is very dark seaweed due to a high content of phenolic compounds. It is likely that the protein is bound to the phenols, giving insoluble compounds that are not attacked by bacteria in the stomach or enzymes in the intestine. *Alaria esculenta* is another large brown seaweed, much lighter in colour and in some experimental trials it has been found to be more effective than *Ascophyllum* meal.

Chapman and Chapman (1980) carried out several feeding trials and studied the protein, fat, ash and fibre of some fresh seaweeds and seaweed meal, as well as the vitamin and mineral content of seaweed meal. Indergaard and Minsaas (1991), also have worked on this aspect.

3. Medicinal uses

Sargassum and *Laminaria* are salty and cold, and enter the liver, lung, and kidney meridians. Both can clear heat, transform phlegm, soften hardness, and dissipate nodules. They can also promote urination and reduce edema. In clinical practice, they are often used together to treat nodules such as goiter and scrofula, (Yang 2002).

One of the best known formulae includes *Sargassum*, *Ecklonia*, and *Laminaria*. It was used to treat a condition of goiter which was so severe that it made the throat look like a large flask. However, these seaweeds have been adopted into formulae for treating other soft swellings, including ovarian cysts, breast lumps, lymph node swellings, lipomas, and fat accumulation from simple obesity (Bensky and Barolet, 1990).

4. Waste water treatment

There are two main areas where seaweeds have the potential for use in wastewater treatment. The first is the treatment of sewage and some agricultural wastes to reduce the total nitrogen- and phosphorus-containing compounds before release of these treated waters into rivers or oceans. The second is for the removal of toxic metals from industrial wastewater (Armisen, 1995). Some seaweed is able to absorb heavy metal ions such as zinc and cadmium from polluted water (Aderhold *et al.,* 1996.). The effluent water from fish farms usually contains high levels of waste that can cause problems to other aquatic life in adjacent waters. Seaweeds can use much of this waste material as nutrient, so trials have been undertaken to farm seaweed in areas adjacent to fish farms.

5. Industrial uses

Industrial uses of seaweed expanded rapidly after the Second World War, but were sometimes limited by the availability of raw materials. Once again, research into life cycles has led to the development of cultivation industries that now supply a high proportion of the raw material for some hydrocolloids. Various red and brown seaweeds are used to produce three hydrocolloids: agar, alginate and carrageenan. A hydrocolloid is a non-crystalline substance with very large molecules and which dissolves in water to give a thickened (viscous) solution. Alginate, agar and carrageenan are water-soluble carbohydrates that are used to thicken aqueous solutions, to form gels (jellies) of varying degrees of firmness, to form water-soluble films, and to stabilize some products, such as ice cream.

Alginate production is by extraction from brown seaweeds, all of which are harvested from the wild; cultivation of brown seaweeds is too expensive to provide raw material for industrial uses. Agar production is principally from two types of red seaweed viz *Gracillaria* and G*elidium.* Carrageenan production was originally dependent on wild seaweeds, especially Irish moss, small seaweed growing in cold waters, with a limited resource base.

Alginate or carrageenans are used in cosmetic products, such as creams and lotions to improve the skin moisture retention properties of the product.

Pastes of seaweed, made by cold grinding or freeze crushing, are used in thalasso-therapy, where they are applied to the person's body and then warmed under infrared radiation. This treatment, in conjunction with seawater hydrotherapy, is said to provide relief from rheumatism and osteoporosis.

Over the last twenty years there have been some large projects that investigated the possible use of seaweeds as an indirect source of fuel. The idea was to grow large quantities of seaweed in the ocean and then ferment this biomass to generate methane gas for use as a fuel. The results showed the need for more research and development, that it is a long-term project and is not economic at present.

6. Antibiotic properties

Seawater itself has antibiotic and healing properties. Seawater also contains dissolved bromine, a compound used in many sedatives (Riekert, 1972). Algae in the sea have properties related to the seawater's medicinal powers, which may explain why marine products have fungicidal, anti-tumor, anti-viral, anti-biotic, hemolytic, analgesic, cardio-inhibitory and other properties.

The halogens, iodine and bromine in particular are effective antiseptics and disinfectants and the tannin polyphenols have antibacterial actions. The polysaccharides present have antitumor and blood anticoagulant actions similar to heparin. (Tressler & Lemon., 1951; Arasaki, 1983).

Furthermore, seaweed extracts have shown antifungal responses that may vary by species, time of harvest, and method of extraction (Khaleafa *et al.* 1975). Hydrolyzed seaweed has been tested on development and spread of powdery mildew *(Erysiphe poplygoni L)* on turnips *(Brassica rapa* L.) by Stepheson (1966). He observed five times less powdery mildew on treated than on control plants.

The application of seaweed extracts to plants resulted in decreased incidence of nematode attack (Tarjn 1977; Morgan and Tarjan 1980). Goatley and Schmidt (1990) suggested that the effect of seaweed extract on stress tolerance may be related to cytokinin and to other non-identified factors.

7. Antioxidant properties

A number of seaweed species have been reported to posses antioxidant properties (Nagai and Yukimoto, 2003). Dietary antioxidants from plants are believed to help prevent aging and other diseases through radical scavenging activity. Almost all the seaweed species have good ability to scavenge hydroxyl radicals (Yan *et al, 1998).* Phloroglucinol and phenolics in marine algae, behave as ROS scavengers, metal chelators and enzyme modulators preventing lipid peroxidation (Rodrigo and Bosco, 2006).

Antioxidants from natural resources have created deep interest among researchers, food manufacturers, and consumers due to their protective role against dreadful disease such as coronary heart dieses and cancer (Loliger, 1991). The search for novel antioxidants with high phenolic contents has become an important issue, because of their role in inhibitory effects on mutagenesis and carcinogenesis in human beings. The antioxidant activity of phenolic compounds is mainly attributed to their redox actions, neutralizing free radicals, quenching singlet and triplet oxygen, or decomposing peroxides (Osawa, 1994).

8. Biochemical composition of seaweeds

According to Ito and Hori (1980) chemical composition of seaweeds varies with species habitats, maturity and environmental conditions. The chemical composition such as water, carbohydrates, proteins, fat, ash and calories from three Hawaiian algae: *Ahnfeltiopsis, Ulva* and *Gracillaria* have been reported by Reed (1970). Studies on the biochemical constituents such as protein, carbohydrates and lipids in green and brown algae have been carried out by many workers from different parts of Indian coast. (Kumar, 1993; Muthuraman and Ranganathan 2004 and Ganesan and Kannan 1994).

Content of protein, nucleic acids, fats and lipids, carbohydrates, sterols, acrylic acid, crude fibre, pigments and inorganic elements of green alga, *Enteromorpha* from Okha (Gujrat) has been analyzed by Parekh *et al.* (1977).

Dhargalkar (1979) reported a high carbohydrate (24-44%) and lipid (6-23%) content in seaweeds in Indian shores and estimated the major metabolites such as proteins, carbohydrates, lipids from *Ulva reticulata*. Murthy and Radia (1978) studied the biochemical contents of *Ulva lactuca, Sargassum wightii* and *Gelidiella acerosa* from Port Okha in relation to ecological factors and presented data for month-wise proteins, carbohydrates, fat, crudefibre, sodium, potassium, calcium and phosphorus. Pillai (1956) reported marked changes in the chemical constituents with change in season, as well as environmental conditions during various phases of plant growth and fruiting cycle.

B. Fertilizer applications

Fertilizer uses of seaweed date back at least to the nineteenth century. Early usage was by coastal dwellers, which collected storm-cast seaweed, usually large brown seaweeds, and dug it into local soils. The high fibre content of the seaweed acts as a soil conditioner and assists moisture retention, while the mineral content is a useful fertilizer and source of trace elements. In the early twentieth century, a small industry developed based on the drying and milling of mainly storm-cast material, but it dwindled with the advent of synthetic chemical fertilizers. Today, with the rising popularity of organic farming, there has been some revival of the industry, but not yet on a large scale.

Seaweed fertilizers are derived from a number of seaweed species around the globe. Most commercial seaweed products, though, are made from fresh cut North Atlantic kelp (*Ascophyllum* spp.) harvested off the coasts of Canada and Norway (Eris *et al.*, 1995). For the liquid extracts, seaweed is often shredded and hydrolyzed under pressure. Preservatives are then added to stabilize the liquid and prevent further decay (Verkleij, 1992). Seaweed meal is dried, milled seaweed prepared usually prepared from brown seaweeds because they are the most readily available in large quantities. Species of *Ascophyllum*, *Ecklonia* and *Fucus* are the common ones. They are sold as soil additives and function as both fertilizer and soil conditioner. They have a suitable content of nitrogen and potassium, but are much lower in phosphorus than traditional animal manures and the typical N: P: K ratios in chemical fertilizers. The large amounts of insoluble carbohydrates in brown seaweeds act as soil conditioner (improve aeration and soil structure, especially in clay soils) and have good moisture retention properties.

Another form of seaweed fertilizer is its liquid concentrate which is produced in concentrated form for dilution by the user. They can be applied directly onto plants or watered in and around the root areas. There have been several scientific studies that proved these products can be effective. The usefulness of the products is associated with the increasing popularity of organic farming, where they are especially effective in growing vegetables and some fruits.

A few number of studies have been carried out to investigate the effect of seaweed fertilizers on a variety of crops. Influence on germination, growth and yield has been reviewed here briefly.

1. Germination

In seed germination studies, seaweed extracts of 0.5 and 1.0% (v/v) improved germination of creeping red fescue *(Festuca rubra)* seeds (Button and Noyes, 1964). High rates, of the fertilizers, above 5% (v/v), retarded seedling emergence. Seaweed extract has also been tested on beet *(Beta vulgaris)* seeds (Wilczek *et al.*, 1982). The treated seed had better germination rates than the control at temperatures of 10, 15, 20, and 30°C.

2. Crop Growth

More than 15 million metric tons of seaweed products are used annually as nutrient supplements and biostimulants in agriculture and horticultural crop production (FAO 2006). Seaweeds and seaweed extracts have long been used in Canadian and European coastal agricultural zones as soil conditioners and foliar sprays to increase crop growth, yield, and productivity (Bokil *et al.* 1974; Stephenson 1974; Senn1987; Crouch and van Staden 1992; Verkleij 1992; Norrie and Keathley 2006).

Seaweed extracts have been reported to increase fresh weight and plant leaf area (Smith and Van Staden, 1983), and root and shoot development of Kentucky bluegrass *(Poa pratensis* L.; Goatley and Schmidt 1990).

Seaweed extract as a foliar fertilizer has been noted to have various beneficial effects on many crops (Button and Noyes 1964). Foliar application of seaweed concentrate to seedlings of *Pinus pinea* L. increased shoot length and weight and decreased in the root to shoot ratio (Atzmon and Van Staden 1994). It was found that root drenches accelerated root growth and increased lateral root dry weight. This indicated that root application of seaweed concentrate improved seedling quality and increased the ability of seedlings to survive transplanting into pots.

Although seaweed products have been utilized in agricultural practices for many years, the precise mechanism by which they elicit beneficial growth responses is still not fully understood (Crouch and Van Staden 1993). Seaweed is known to contain a wide range of minerals but does not satisfactorily account for the total changes in mineral content of plants treated with seaweed extract (Blunden 1977). Seaweed contains both carbohydrates which stimulate plant growth and those which might reduce growth (Blunden and Woods 1969). Moreover, some of these effects have been attributed to the presence of growth substances such as cytokinins, which are known to occur at relatively high levels in various seaweeds and commercial seaweed preparations (Blunden and Wildgoose 1977; Tay *et al.* 1987). Brain *et al.* (1973) showed a high cytokinin activity in a commercial seaweed extract, which could be responsible for many effects such as protein and CO_2 metabolism, enzyme formation, leaf aging and senescence, shoot elongation, and fruit set (Torrey, 1976). Cytokinins also may have some physiological regulatory role in nutrient mobilization in plants (Kuiper and Staal 1987). Recent studies have shown the presence of auxins in seaweed concentrates (Sanderson *et al.* 1986; Crouch *and* Van Staden, 1993). Seaweed has also been reported to contain a-tocopherol (Jensen 1969), 3-carotene, niacin, thiamin, and ascorbic acid (Jensen 1972).

In a growth chamber study with wheat, seaweed concentrate from *Ecklonia maxima* increased root and shoot dry mass, kernel mass, kernels and spikelets number, and culm thickness and reduced senescence (Nelson and Van Staden 1986). On the other hand, the results of field experiments indicated no significant increase in wheat yield in response to seaweed extract from *Durvillaea potatorum* or *Ecklonia maxima* (Myers and Perry 1986). Similar responses to seaweed extract application on barley *(Hordeum vulgare)* plants are reported where no effect on the yield was observed (Taylor *et al.* 1990).

Many of the beneficial effects of seaweed treatment on plants resemble those obtained following the application of cytokinins (Blunden and Wildgoose, 1977). This has prompted some workers to speculate that this group of plant growth regulators is responsible for most of the improved performance of treated plants.

Many organic molecules in seaweed concentrates promote the uptake of nutrients. In peppers (*Capsicum annuum* L.) treated with soil applied seaweed extract, an improved utilization of trace elements was found by Lynn (1972). Researchers have found that seaweed extract applications can lead to increased plant growth and changes in plant tissue composition. In greenhouse cucumbers *(Cucumis sativus* L.), when seaweed concentrate was applied as a root soak at transplant and as a weekly foliar spray, an increase in overall plant dry mass and root growth was reported (Nelson and Van Staden, 1984). Tourte *et al.* (2000) observed in organic tomatoes (*Lycopersicon esculentum* Mill.) sprayed four times during the season with a seaweed/fish blend, significantly higher foliar NO3 concentrations than the controls, although yield or fruit quality was not improved.

3. Yield

A variety of plants have shown an overall increase in yield in response to seaweed application. Foliar application of seaweed extract increased harvestable bean (*Phaseolus vulgaris* L.) yields by an average of 24% (Temple and Bomke, 1989), staked tomato yields up to 99% (Csizinszky, 1984), early yield of one variety of greenhouse cucumber 45% (Passam *et al.*, 1995), and greenhouse tomato total fruit fresh weight by 17% (Crouch and Van Staden, 1992). Some researchers have reported that the application of seaweed extract did not affect yield at all. For example foliar sprays of seaweed extract failed to increase yield of wheat (Myers and Perry, 1986), onion (Feibert *et al.*, 2003), and field tomato (Tourte *et al.*, 2000).

Blunden and Wildgoose (1977) found that spraying potato plants *(Solanum tuberosum)* with seaweed extract gave similar increase in yield to that with kinetin which is a cytokinin.

4. Environmental stress

Application of seaweeds stimulate plant growth and development and improve resistance to environmental stresses. (Schmidt and Osborn 1993) The effect of seaweed on plant growth under stress conditions has been investigated. Wheat grown under water stress yielded higher grain in response to seaweed application (Mooney and Van Staden 1985). Improved root and shoot growth of turf-grass (Zhang, 1997) and membrane permeability in ryegrass *(Lolium perenne;* Yan 1993) contributed in enhancing plant stress tolerance.Under K deficiency, Becket and Van Staden (1989) found that application of seaweed concentrate improved both grain number and grain weight. However, no significant increase in yield was observed under sufficient supply of potassium.

Nabati *et al.* (1994) reported increased salt stress tolerance in Kentucky bluegrass in response to seaweed extract. According to Hall, (1991) proper application of seaweed extract may enhance plant growth and tolerance to water stress.

The success of seaweed extract in crop production appears dependent on a number of factors, including the crop, the rate of seaweed application, the composition of the seaweed extract used, and the application method (soil or foliar applied). It is generally agreed that seaweed extracts could have some beneficial effects as supplemental foliar fertilizers. The adoption of the practice, however, is limited due to the cost of the sprays, the labour of application, and the inconsistent crop responses.