THE USE OF THE KELP, *Macrocystis integrifolia*, AS A SOIL AMENDMENT AND FOLIAR SPRAY UPON SELECTED CROPS

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ABSTRACT

In this investigation the coastal B.C. kelp, Macrocystis integrifolia, was evaluated for its potential use as a soil amendment and foliar spray in crop production.

The kelp soil amendment was applied fresh to a fine-textured deltaic soil with applications of 0, 7.5, 15, 30, 60 and 120 t ha^{-1}. Soil chemical, physical, crop growth and nutritional responses were characterized over a two year period. Beans (Phaseolus vulgaris) were planted in the first year and peas (Pisum sativum) were planted in the second year. Plant growth responses included reduced yields, emergence and flowering with the 120 t ha^{-1} application and increased plant moisture content with increasing kelp applications. Nutritional responses included increased plant elemental concentrations and uptakes of Na, K and Cl with increasing soil applications of kelp. Soil responses to increasing applications of kelp included sharp increases in soil water-soluble salts, Cl, NO_3-N, exchangeable K and Na, and a decline in soil pH. Subsequent greenhouse experiments suggested that phytotoxic effects from the 120 t ha^{-1} kelp applications were primarily

induced by high levels of soluble salts, but an unknown phytotoxic substance may be implicated. Soil aeration increased with kelp application up to 60 t ha^{-1}, but declined with the 120 t ha^{-1} application.

The use of *M. integrifolia* as a processed concentrate for subsequent dilution with water and foliar application (2 and 4 L ha^{-1}) to the bean (*P. vulgaris*) crop resulted in increased harvestable bean yields in each of two field seasons. Evidence is presented which supports the theory that growth promoting phytohormone-like substances extracted from the kelp may, in part, be active constituents of the kelp concentrate. Field crop nutritional responses to kelp foliar sprays included reduced shoot elemental concentrations, but increased uptakes, suggesting greater dry matter accumulation per unit element. Crop growth and nutritional responses between growing seasons were not consistent. A greenhouse experiment demonstrated that many of the kelp foliar spray effects upon crop growth, development and nutrition could be dependent on soil moisture regimes.

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CHAPTER ONE

LITERATURE REVIEW

1.1 Historical Background

Various large brown algae (Phaeophyta: Laminariales) known as kelps are commonly used as a soil amendment upon the Atlantic coastal lands of France, Ireland and Scotland. The greatest applications are along the entire coast of Brittany and nearby Channel Islands where kelp harvests are rigidly controlled (Chapman, 1970). In 1681, a royal decree was issued in France regulating the conditions under which kelp could be collected. The decree specified the type, location and use of the kelp. The success of kelp soil amendments is particularly evident in the Channel Islands. There, kelp is mixed with sand and applied to areas previously lacking productive soils (Stephenson, 1968).

In Europe, during the seventeenth century, a kelp trade had developed. At this time the word "kelp" was used to refer to the burnt ash or potash of the large brown algae; today it describes these algae themselves. The algae of Europe used in the kelp trade were various species of Laminaria, Fucus and Ascophyllum. In 1910, because of

difficulties with German supplies, North Americans began to use kelp (Laminaria) off the Pacific and Atlantic Coasts for the production of potash. The kelp fertilizer trade failed once fertilizers from inorganic sources could be obtained economically.

Despite the collapse of the kelp fertilizer market, the established kelp trade of Europe and North America formed the background for the current seaweed colloid industry. Today the colloid industry production of carrageenan and algin, used primarily as stabililzers in the food industry, is a billion dollar industry (Chapman, 1970; Naylor, 1976). In California approximately 150,000 wet tonnes of kelp (Macrocystis) are harvested annually for production of alginates (North et al., 1982). In the Canadian maritimes, approximately 8,000 wet tonnes of Chondrus are harvested annually for production of carrageenan (Pringle and Semple, 1983).

At present, there are several companies which process and produce kelp products for agricultural use (Table 1). Kelp foliar sprays were first marketed during the 1950's and 1960's. The manufacturers' claims of the benefits that could be achieved by the use of their products were not well received by the academic community, for there was no scientific evidence to support the claims.

TABLE 1. COMMERCIAL KELP FOLIAR SPRAYS

COMMERCIAL NAMES	ORIGIN/TYPE OF KELP		COUNTRIES MARKETED
Marinure/Algit/ Algifert	Norway	- Ascophyllum	[1]EEC/Japan/British Commonwealth
Nitrozyme/Seacrop 16	USA	- Ascophyllum	USA/Canada
SM3	UK	- Ascophyllum/ Laminaria/ Fucus	BritishCommonwealth/ EEC
Seasol/Agrikelp	Australia	- Durvillea	Australia/USA
Goe-mar	France	- Laminaria	France
Kelpak	South Africa	- Ecklonia	South Africa/ British Commonwealth/ EEC

[1]European Economic Community

Manufacturers contended that micronutrient constituents in the kelp, when applied as a foliar spray, were responsible for many of the observed beneficial effects on plant growth (British Patent 664,989; Stephenson, 1968). Favorable reports from farmers prompted scientific inquiry (Booth, 1966). It is noteworthy that the scientific opinion of the time did not fully recognize that plant nutrients could be absorbed via foliar spray (Booth, 1966).

The scientific community's view was best described by Fogg when he wrote, "The results with seaweed may savour a little of muck and magic, but seem definite and worth investigation" (cit. Abetz, 1980). As research evidence has been compiled in support of some of the manufacturers claims of increased yields, the views of agricultural scientists have changed, but the use of kelp is still controversial. Today the many unsubstantiated claims by manufacturers and/or distributors still make many farmers skeptical of kelp use and limit scientific investigation. The experimental evidence will be discussed in detail further in the text.

1.2 Types of Kelp Applications in Agricultural Crop Production

The chemical composition of kelp is very different from that of vascular plants. The ash content varies from 25% to 35% dry weight compared with 5% to 6% in hay and 4% or less in various grains. The fat and protein content is approximately the same as in land vegetation (Senn and Kingman, 1978). Kelps are rich in carbohydrates, which differ from those found in higher plants; algins, laminarans, fucoidans and mannitols predominate (Blunden and Woods, 1969; Whyte, 1978).

1.2.1 Soil Amendment

After winter storms large quantities of vegetative debris called "cast" can be found along coastlines where abundant marine algal resources exist. Cast has been collected in many parts of the world by farmers and gardeners and applied directly to the soil. This is the oldest and most common form of seaweed soil amendment for crop production.

In areas such as Norway, Normandy, Brittany, Wales,

Scotland, England, Ireland and the Channel Islands, large supplies of kelp exist and are harvested, left to dry and transported to the neighboring farms. Rapid applications of freshly harvested kelp, as opposed to composted kelp are said to give the best results in crop production (Myklestad, 1964; Booth, 1965; Stephenson, 1968; Guiry, 1981).

Commercially available seaweed soil amendments (liquids, powders and pellets) also exist, but their use is primarily restricted to horticultural and domestic home gardening applications (Aitken and Senn, 1965).

1.2.2 Crop Foliar Sprays

The second type of farm use of kelp is foliar sprays. Foliar applications tend to vary with manufacturers, but in general the manufactured kelp extracts or concentrates are diluted with water and applied at 2 to 10 L ha^{-1} each application. Two to four applications applied early in the crop development are usually recommended.

The first two commercial kelp foliar sprays were "Maxicrop" and "SM-3" manufactured in the late 1950's by Maxicrop Ltd. and Chase Organics Ltd., respectively.

Shortly afterwards another producer, Alge Produkter of Norway, began to manufacture a kelp foliar spray and supplied the product under a variety of trade names. All three companies' products are so-called kelp "extracts" and employ a method of production which involves alkali hydrolysis, temperature greater than 100^{o}C and slight pressures of approximately 500 kPa to cook and disintegrate the harvested kelp. The separation of the broth from the residue is achieved by settling and siphoning or filtering. It is the broth or liquid kelp "extract" that is bottled and ready for use after dilution with water as a foliar spray onto crops (British Patent 664,989; Stephenson, 1968). The manufacturers usually add formaldehyde (0.1% by volume) to prevent fermentation (Stephenson, 1968).

Two relatively new companies marketing kelp extracts are Atlantic Labs of Maine (U.S.A.) and Tasbone Pty. of Australia with the trade names of "Nitrozyme" or "Sea Crop 16" and "Seasol", respectively. All these companies produce a kelp extract using the basic methods discussed above, although differences do exist with respect to temperatures, pressures, types of hydrolyzing agent, quantities and type of kelp used by the individual manufacturers.

One company, Kelp Products Ltd. of South Africa, established in the late 1970's, does not produce a kelp extract, but produces a kelp concentrate called "Kelpak 66". The method simply uses freshly harvested kelp which is washed, ground, chopped and pressure (greater than 40,000 kPa) homogenized to disintegrate and reduce the particle size of the kelp to approximately 50 µm. The process generates much lower temperatures than that of the hydrolysis method (South African Patent 78/3281). The patent claims that the advantage of the invention is that organic active constituents, such as plant growth regulators, are less likely to be denatured because high temperatures are not involved. Such a claim has never been substantiated.

1.3 Overview of Experimental Results

1.3.1 Kelp as a Soil Amendment

The use of fresh kelp as a soil amendment has received little attention from the agricultural science community and many of the claims reported from its use are poorly documented. Booth (1965) described the use of seaweed as a soil amendment as follows, "While there is an abundance of

evidence to show that seaweed is widely used as manure, there is little scientific evidence to support the traditional use of seaweed."

The use of raw kelp in and around the British Isles is not confined to subsistence agriculture. Kelp additions to the soil are commonly practiced in Cornwall, Ayrshire and East Lothian. In Cornwall, the kelp is mixed with straw and composted; in Ayrshire, freshly harvested kelp is spread over the soil in the fall; and in East Lothian, kelp is stacked in heaps and left to rot over winter prior to adding to the soil (Booth, 1965).

Vast quantities of the kelp Lamenaria hyperborea (Gunn.) Foslie exist along the shores of Norway. In past years the use of kelp as a soil amendment was common practice but ceased with the advent of inorganic fertilizers. More recently the use of this kelp as a soil amendment supplemented with inorganic fertilizers has been renewed as a means to add organic matter to the soil and to improve the soil structure (Myklestad, 1963).

In Ireland, kelp has been gathered for hundreds of years and up until the present century was burned to produce

potash as a source of fertilizer (Guiry, 1981). Several other areas which practice the use of kelp as a soil amendment were discussed at the beginning of the text (Section 1.1).

Francki (1960a, 1960b and 1964) investigated the use of the algae Pachymenia himantophora J.Ag. and Durvillea antarctica (Chamiss.) Hariot as soil amendments to five different soils in which greenhouse tomatoes (L. esculentum) were planted. Yields were reduced by D. antarctica in all soils and P. himantophora increased yields in only two soils. Francki attributed the reduced yields to Mn toxicity as soils were dispersed and became waterlogged. Nitrogen immobilization was also suspected as a cause of poor growth as the C/N ratio of the seaweeds was ≈30.

Offermanns (1968) and Caiozzi et al. (1968) reported increases in Fe and P availability in calcareous soils which were incubated with the kelp Macrocystis integrifolia Bory.

Blunden et al. (1968) investigated the effects of the processed kelp (Laminaria spp) extract SM-3 as fertilizer upon the growth of mustard (Brassica hirta Monench). They concluded that the growth-promoting effects of this extract

were primarily due to the inorganic constituents present in the extract, primarily cations and in particular, K.

1.3.2 Effects of Kelp Extracts and Concentrates on Seeds

Button and Noyes (1964) using the kelp (Laminaria spp) extract "SM-3" demonstrated that pretreatment of creeping fescue (Festuca rubra L.) seeds with 0.5% and 1% (v/v) extract solutions increased the rate of seedling emergence. Extract solutions greater than 5% (v/v) were detrimental to growth and at 18% (v/v) no seedlings emerged. Senn and Skelton (1969) reported that seeds of loblolly pine (Pinus taeda L.) and sacred bamboo (Nandina domesticum Thumb.) when treated with the Norwegian kelp extract of high solution concentrations had increased respiration rates, but limited germination. However, germination improved as solution concentrations were decreased. The authors concluded that kelp extracts may have a potential use to enhance the germination of certain seeds.

Donald (1981) reported that soaking seeds of Mexican pine (Pinus patula Schiede et Deppe) for 24 h in a 0.2% (v/v) solution of the kelp (Ecklonia maximum (Osbeck) Papenfuss) concentrate "Kelpak 66" improved germination and

reduced dormancy.

1.3.3 Effects of Kelp Extracts on Shelf-Life of Fruit

Povolny (1969, 1972 and 1976) conducted several experiments investigating the effects of pre-harvest spraying with the Norwegian kelp (Ascophyllum nodosum (L.) LeJolis) extract on storage and ripening of apples (Malus domestica L. cv. Cox's and Goldparmane) peaches (Prunus persica Stokes), apricots (Prunus armeniaca L.) and tomatoes (Lycopersicum esculentum Mill.). Applying two 0.8% (v/v) kelp extract solutions to Cox's apples 12 and 26 days prior to harvest increased the shelf life, hardness of fruit and fruit diameter. There were no effects upon acid or sugar content. No treatment effects were recorded with Goldparmanes apples. Pre-harvest spraying of 0.5% (v/v) kelp extract solution to peach and apricot trees resulted in harder flesh of both fruits at harvest, but had no effect on storage losses of either fruits. Spraying tomato plants with 0.5% (v/v) kelp extract solution resulted in a 15% increase in yield. Storage losses after four weeks were 39% less than the control.

It was this early research documenting the

effectiveness of dilute kelp extracts on seed germination, respiration and emergence and increased shelf-life of harvested fruits which led Booth (1969) to postulate that phytohormones, particularly cytokinins, may be active constituents of these kelp extracts.

Blunden et al. (1978) investigated the effects of postharvest dippings of fruit in the kelp (Laminaria spp) extract "SM-3" and contrasted this with dipping fruit in a cytokinin solution. The post-harvest treatment of eggplant (Solanum melongena L.), avocado (Persea gratissima Gaertn.) and pear (Pyrus commmunis L.) with kelp extract or cytokinin solutions had no effect on ripening. Bananas (Musa paradisiaea M.) and mangoes (Mangifera indica L.) which were treated with cytokinin or kelp extract solutions ripened faster. Post-harvest treatment of pepper (Capsicum frutescens L.) gave conflicting results with the kelp extract slowing the ripening process and cytokinins accelerating ripening. With lime (Citrus aurantium L.), both the kelp extract and cytokinin solution reduced the rate of fruit ripening. The authors concluded that while there is evidence to suggest that some physiological responses were similar to those of exogenously applied cytokinin, there was also evidence to suggest that other

plant growth regulators were also present.

1.3.4 Effects of Kelp Foliar Sprays on Crop Growth, Development and Nutrition

Povolny (1971) sprayed greenhouse cucumbers (Cucumis sativus L.) with a 0.2% (v/v) solution of the Norwegian kelp (A. nodosum) extract eight times with 7- to 10-day intervals between sprayings. A 17% increase in harvestable yield of cucumbers resulted. Similarly, Nelson and van Staden (1984a) applied a 0.2% (v/v) solution of the kelp (E. maxima) concentrate "Kelpak 66" to greenhouse cucumbers eight times with seven-day intervals between spraying. Total plant dry matter increased 56%, with an increase in root dry weight of 99%. Treated plants had greater leaf elemental P and lower N concentration. Treated plants had a root/shoot ratio of 3.8 and the controls had a ratio of 2.3. The authors suggested a two-fold action of the kelp treatment; first, stimulation of root growth at the expense of shoot growth and, second, increased overall photosynthetic accumulation efficiency of the plant. Foliar application during fruit development caused an initial inhibition of fruit development and Nelson and van Staden noted that foliar applications during this stage of

development may be inappropriate.

Blunden et al. (1979) applied the kelp (Laminaria spp) extract "SM-3" at 11.2 L ha^{-1} (1.0% (v/v) solution) to 16 different varieties of field sugar beets (Beta valgaris var maritima L.). The kelp-treated plants had greater root sugar content, but similar root yields to the control. The N and K concentrations of the extracted juice were also reduced by the kelp treatment. Blunden and Wildgoose (1977) conducted potato (Solanum tuberosum L.) field trials using the same kelp extract and contrasted its foliar treatment effects to its previously determined cytokinin-like phytohormone activity of 125 mg L^{-1} (kinetin equivalence). Both the kelp extracts and kinetin solutions were diluted with water and applied at kelp extract equivalents of 11.22 and 5.61 L ha^{-1}, respectively. Both the kelp extract and kinetin treatments increased the yields of potatoes with the 11.22 L ha^{-1} application having the greatest effect. These researchers concluded that the phytohormone cytokinin may be an active constituent of kelp extracts, although it was not demonstrated that the yield responses were caused by the same plant physiological effects, such as delayed senescence or altered shoot/root ratios.

Kotze and Joubert (1980) investigated the growth and nutritional effects of the kelp (E. maxima) concentrate "Kelpak 66" on greenhouse grown rye (Secale cereale L.) and cabbage (Brassica oleracea var. capitata L.). The plants were potted into soils at two different fertilizer applications (0.042 and 0.42 g of 3-1-5 fertilizer per 350g of dry loam soil) and sprayed every two weeks with 0.3%, 0.2% and 0.1% (v/v) kelp concentrate solutions. Root growth increases were recorded with cabbage plants which had received higher fertilizer applications only. No effects upon shoot growth were measured. Rye plants grown in the higher fertility soil and sprayed with the 0.2% and 0.1% kelp solution had greater dry shoot and root weights. Plant shoot uptake of Ca, Mg, K, Zn and Cu only increased in the higher fertility soil. The authors concluded that kelp foliar treatments were most effective for plants which were grown in soils with adequate fertility and that the response could not be attributed to mineral nutrition of the kelp. Plant responses would probably be dependent on type of plant, weather conditions and time of application during crop development. Dilution of the concentrate prior to application also appears to be an important factor controlling crop response, with higher dilutions having the greater growth-promoting effects.

Featonby-Smith and van Staden (1983a) also investigated the interactive effects of spraying a 0.2% (v/v) kelp (E. maxima) concentrate solution of "Kelpak 66" and soil fertilizer applications on greenhouse grown swiss chard (Beta vulgaris var. cicla L.). Fertilization enhanced the yields of the crop over those growing in unfertilized soils, but additional increases in plant yields were obtained with kelp treated plants grown in well fertilized soils. These researchers also measured the cytokinin-like activity of the plant root and shoot. The shoot cytokinin-like activity was inversely related to shoot yield, with the kelp-treated plants having the lowest activity. Root cytokinin-like activity was lower for those plants which had received both the fertilizer and kelp foliar treatment and greater for those plants which had only received either fertilizer or kelp foliar treatments. The authors concluded that low shoot levels of active cytokinins in kelp-treated plants suggest that these compounds were being rapidly metabolized during periods of active shoot growth and that the provision of N resulted in an increase in the export of cytokinins from the root to the shoot.

Nelson and van Staden (1984b) applied a 0.2% (v/v) kelp (E. maxima) concentrate solution of "Kelpak 66" eight times

to wheat (Triticum aestivum L.) plants grown in the greenhouse. Kelp-treated plants had greater grain weights and greater thickness of the vascular bundle, but similar overall culm diameters and heights to untreated plants. The authors mention the potential use of the kelp concentrate to increase straw strength and that other active compounds, besides cytokinin, may also be implicated.

Gupta and MacLeod (1982) investigated the effect of the kelp (A. nodosum) extract "Sea Crop 16" upon the yields of wheat (T. aestivum) and pea (Pisum sativum L.) under both field and greenhouse conditions. Yields of neither crop were affected by the kelp foliar application. The lack of a growth response was attributed, possibly, to favourable growth conditions, since environmental stress has been hypothesized as a possible factor controlling the efficacy of the treatment.

Featonby-Smith and van Staden (1987) investigated the effects of the kelp (E. maxima) concentrate "Kelpak 66" on barley (Hordeum vulgare L.) grown in a growth chamber. Both the 0.2% and 4% (v/v) solutions, applied once two weeks after emergence, were effective in increasing grain yields. The grain yield increase with the 0.4% solution was

primarily related to increased number of ears, whereas the yield increase caused by the 0.2% solution was primarily related to increased number of grains per ear. The nitrogen content of the grain was reduced as yields were enhanced by the kelp treatment. These results demonstrate the importance of dilution of the kelp concentrate prior to application upon the yield components which are affected. The decreased N concentration of the grain in relation to dry matter yield increases suggest a lack of available N to maintain grain protein at the higher yields or a nutritional dilution effect (greater dry matter accumulation per unit N).

Featonby-Smith and van Staden (1983b) applied a 0.2% (v/v) solution of the kelp (E. maxima) concentrate "Kelpak 66" to greenhouse tomato (L. esculentum) plants grown in nematode-infested soils. The first foliar spray treatment occurred at transplant (0.1 m height seedlings) with four other foliar treatments ranging from two to five sprays at 15-day intervals between applications. Growth of plants which received one or two sprays was not affected; however, root and shoot weights of plants which received three to five sprayings had increased by approximately 80%. These results suggest that numbers and/or timing of applications may also be an important factor controlling the efficacy of

kelp foliar treatment. Whether the nematodes caused a stress which elicited a plant response to the kelp foliar treatment is not known.

Abetz and Young (1983) applied the kelp (A. nodosum) extract "Maxicrop" at 3, 6 and 9 L ha-1 to field-grown lettuce (Lactuca spp) and cauliflower (Brassica oleracea var. botrytis L.). Kelp extract treatments had no effect on yields of cauliflower, but significantly affected development. Kelp treated plants formed fewer heads, but the weight of the individual heads increased.

Erasmus et al. (1982) investigated the combined effects of spraying simultaneously the ^{14}C labelled herbicide 2-methyl-4-chlorophenoxyacetic acid (MCPA) and the kelp (E. maxima) concentrate "Kelpak 66" to determine whether kelp treatments would adversely affect the herbicide absorption if it was to be used in a tank mix. The test plants were beans (Phaseolus vulgaris L.) and wheat (T. aestivum). Each was treated with and without 0.1% and 0.2% (v/v) solutions of kelp concentrate and with 1.0 ul [^{14}C] MCPA and incubated for 24 h in the greenhouse prior to harvest. With wheat the majority of the recovered radioactivity was in the leaf wash with the kelp treatment doing little to hinder or promote

the uptake of MCPA. With the broad-leafed bean plants MCPA was taken up and distributed throughout the plant. The 0.1% solution of kelp concentrate induced the greatest bean plant uptake of MCPA. The authors concluded that the selectivity of the herbicide was not detrimental when used in tandem with the kelp concentrate.

1.3.5 Active Constituents of Kelp Foliar Sprays

Blunden (1977) examined the elemental compositions of kelp extracts and concluded that kelp foliar sprays could not supply a significant proportion of the annual requirements of macronutrients to a crop. Blunden states that the spray could possibly supply an amount of limiting nutrients to correct a marginal deficiency only. It is because kelp concentrates and extracts are used at such low concentrations and that the recorded growth regulating responses (i.e. enhanced plant emergence, growth, seed germination and respiration, altered development and delayed ripening) typify phytohormonal responses, that plant growth regulators or phytohormones are believed to be active constituents.

Sanderson and Jameson (1986) measured the cytokinin-

like activity (tobacco callus bioassay; kinetin equivalence) of the kelp (A. nodosum) extract "Maxicrop" at 1.3 mg L^{-1} ($\approx 10^{-6}$ M). Much of the activity co-chromatographed with zeatin, zeatin riboside, isopentenyladenine, glucosides and their dihydroderivatives. The authors contend that the cytokinins contained in "Maxicrop" are physiologically active and "if taken up by the plant, would not immediately be degraded to inactive compounds" and that the quantities present are "still of sufficient concentration to be physiologically active". Whether these compounds are physiologically active under field conditions has yet to be demonstrated.

Featonby-Smith and van Staden (1983b) measured the cytokinin-like activity (soybean callus bioassay; kinetin equivalent) of "Kelpak 66" at 516 ng in 20 g fresh weight of kelp (E. maxima) concentrate ($\approx$26 µg L^{-1} or $\approx 10^{-7}$ M). Much of the activity co-chromatographed with zeatin and zeatin riboside and subsequent high pressure chromatography analysis also detected zeatin, zeatin riboside, dihydrozeatin and isopentenyladenine. Featonby-Smith and van Staden (1984) also investigated, using paper chromatography and soybean callus bioassay techniques, the seasonal cytokinin compositional changes in the kelp E.

maxima from which "Kelpak 66" is produced . Qualitative and quantitative variations in plant cytokinin composition were similar to those of terrestrial plants with much of the cytokinin present as glycoside during periods of little growth and as "free" cytokinins during periods of rapid growth. The concentration of plant growth regulators in the kelp extract or concentrate appear to be dependent on the seasonal harvest date or the kelp's physiological age at the time of harvest.

Finnie and van Staden (1985) applied 1%, 0.25%, 0.17% and 0.1% (v/v) solutions of the kelp (*E. maxima*) concentrate "Kelpak 66" to *in vitro* cultured tomato (*L. esculentum*) roots. The 1% solution was inhibitory, whereas the 0.25% and 0.17% solutions were stimulatory with the 0.1% solution having no effect. These researchers were able to mimic the same growth responses with zeatin. Other phytohormones such as auxins, abscisic acid and gibberellic acid had no such mimicking effect. As was the case with the kelp concentrate the high solution concentrations of zeatin ($>10^{-6}$ M) were inhibitory, whereas lower concentrations (10^{-8} and 10^{-10} M) were stimulatory. The kelp concentrate was also autoclaved or ashed prior to application. Ashing resulted in a complete loss of any root growth response but autoclaving

had no effect. These results suggest that the active constituents of this investigation are relatively stable organic compounds. When the concentrate was paper chromatographed and the eluate of each strip applied to the tomato roots there were two fractions which were stimulatory. The fraction which contained polar compounds had the greatest effect upon root length, while the less polar fraction had its greatest effect upon lateral root initiation. The less polar fraction also co-chromatographed with zeatin. The authors concluded that the E. maxima kelp concentrate contains more than one active constituent, each of which may cause different growth effects. It would be incorrect to assume that the mimicking effects of the kelp concentrate relative to known cytokinin are via the same mechanism. The fact that the kelp concentrate effects upon tomato root growth was over one order of magnitude (1% to 0.1% solution concentration), whereas the zeatin concentrations were over four orders of magnitude (10^{-6} to 10^{-10} M), could suggest they are not. The dilution effects obtained with the kelp concentrate could have been related to growth inhibitors, which upon increasing dilution become less effective than that of the growth-promoting substance(s).

Tay et al. (1985) isolated, identified and quantified several cytokinins in the kelp (Durvillea potatorum (Labill.) Aresch.) extract "Seasol" (or "Agrikelp") using heavy isotope [^{3}H]-labelled cytokinins to determine extraction recovery and bioassay detection procedures coupled to gas chromatography-mass spectrometric analysis (GC-MS). Trans-zeatin, trans-zeatin riboside, dihydrotrans-zeatin, dihydrotrans-zeatin riboside, isopentyladenine and isopentenyladenosine were identified at concentrations of 0.70, 7.01, 1.06, 36.6, 2.06 and 15.9 μg L^{-1} of extract, respectively. This was the first definitive report on the identification of cytokinins in algae and that the observed low quantities ($\approx 10^{-7}$ M) are insufficient to be the only compounds responsible for beneficial effects of "Seasol" upon plants, although no supporting evidence was presented for the latter argument.

Cytokinin-like compounds have also been detected in the kelps Ecklonia radiata (C. Ag) J. Ag and Fucus vesiculosus L. (Jennings, 1969a). Cytokinins have also been detected in the seawater in which these plants grow (Kentzer et al., 1980). Auxin-like and gibberellin-like substances have been detected in numerous marine algae (Augier, 1976a and 1976b; Taylor and Wilkinson, 1977). In addition to these plant

growth promoters, plant growth antagonists have also been detected. Jennings (1969b) extracted an unidentified compound from the kelp E. radiata, which inhibited the stem elongation of dwarf maize plants treated with gibberellic acid. Gibberellic acid normally promotes stem growth of these plants. The author concluded that the compound acted specifically as an antagonist to gibberellin-controlled growth. Nelson and van Staden (1984b, 1985) observed a thickening of the culm diameter of wheat (T. aestivum) plants which were treated with the kelp (E. maxima) concentrate "Kelpak 66" and suggested this response might be attributed to 1-aminocyclopropane-1-carboxylic acid (ACC), which they detected in the kelp concentrate at 9.29 nmol ml^{-1}. ACC is the precursor to the volatile phytohormone ethylene which the authors indicate can also cause a thickening of wheat culms. The authors doubt that cytokinins are the only active constituents of kelp concentrates, particularly in view of the many plant physiological and developmental effects caused by kelp applications.

A great amount of caution must be used when comparing bioassay activity levels of phytohormones presented by various researchers. Bioassay results can be very

misleading for they are influenced by many factors such as the presence of growth inhibitors, purity of extracts and the presence of salts or other unidentified compounds which can mimic what are believed to be phytohormone responses (Norris, 1976). Bioassays were never intended for quantification, but for relative comparisons between extracted samples or to detect phytohormones in particular fractions prior to physiochemical methods of quantification. When bioassay results are presented as the only means of analysis the term "like" should be used as the suffix to the particular phytohormone in question.

1.4 Summary

Although kelp has been used in agriculture for hundreds of years, research efforts are relatively recent. With the increased use of inorganic fertilizers in the past several decades the common practice of using kelp as a soil amendment or for the production of potash has decreased, although its use as a soil amendment still persists in some coastal regions. Documented field trials in which kelp has been used as a soil amendment are relatively few. This is probably related to (a) the few geographic regions in which abundant supplies of the resource are available, (b)

traditional uses having been lost with the advent of inorganic fertilizers and (c) the difficulty of conducting large field plot trials since they involve vast quantities of kelp.

Various species of kelp have also been processed into extracts or concentrates for subsequent dilution with water and applied as a crop foliar spray. Treatment effects on crop yield, fruit shelf-life, seed germination and development have been documented. The active growth-promoting or regulating components have yet to be identified, although many of the plant developmental responses suggest that several plant growth-regulating substances, in particular cytokinins, may be implicated. It has yet to be conclusively demonstrated that such compounds detected in the concentrates or extracts are directly responsible for crop responses. The concentration of the kelp in solution also appears to be an important factor controlling its efficacy in promoting crop growth and development. High concentrations of kelp have been found to be inhibitory, while lower concentrations promote crop growth.

Evidence suggests that kelp foliar treatments are most

effective when soils are fertile or adequately fertilized. Several foliar sprays are usually required and best results have been obtained with early foliar applications, as opposed to foliar applications during plant maturation. The interaction between timing and quantities of application to various crops has yet to be fully investigated.

Not all plants tested respond to kelp foliar treatments, but whether this is due to the type of crop or to the kelp concentrations in solution, quantity and/or timing of application to the crop has yet to be determined. Many of the positive growth and developmental responses to kelp foliar treatment have been conducted under controlled growth conditions (i.e. greenhouse and growth chamber experiments), whereas positive responses in field experiments have been relatively few. Such results suggest that growth-limiting environmental factors (eg. light, temperature, drought, water-logging, salt, disease and/or pests) may also be important factors controlling the efficacy of kelp foliar treatments.

CHAPTER TWO

KELP FROM BRITISH COLUMBIA COASTAL WATERS FOR USE IN AGRICULTURAL CROP PRODUCTION

2.1 Introduction

Coastal British Columbia has one of the most abundant and diverse populations of salt water algae. This abundance and diversity is related to the nutrient rich medium in which the algae grow. Nutrients are brought into this marine environment primarily as a result of upwelling and surface water discharge. Upwelling is related to prevailing winds creating currents along the continental shelf which bring nutrients up to the coastal fringes.

The large established and presently unexploited kelp beds (Figure 1) of coastal British Columbia are literally the "forests of the sea" and are an integral part of marine coastal environment. An understanding of the life history of these algae and how they integrate with their environment is fundamental if we are to manage them as a renewable resource and make appropriate decisions as to how, when and where to harvest.

KELP SURVEY ALONG COASTAL BRITISH COLUMBIA

(Survey dates in brackets; after Coon, 1983)

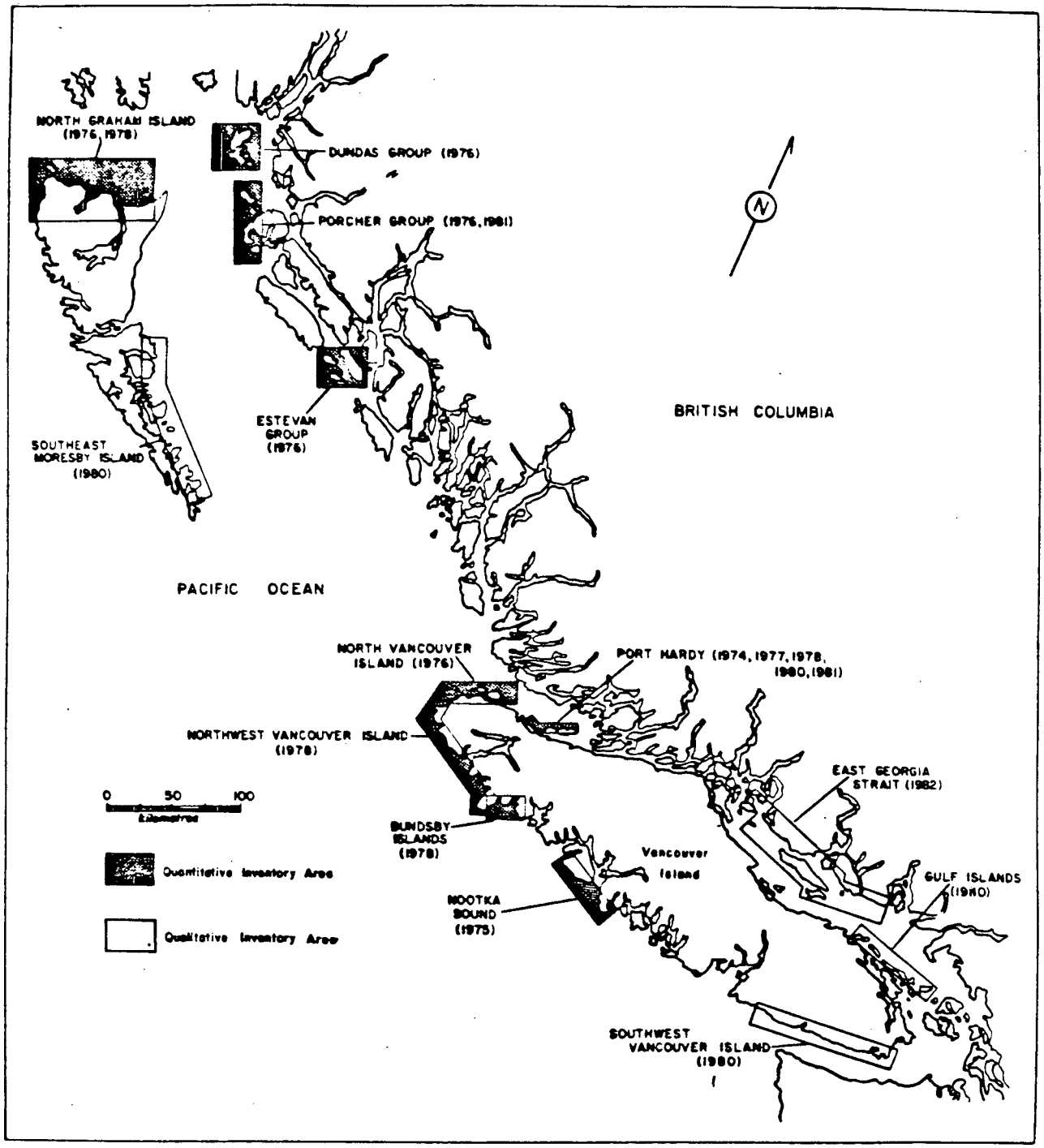


FIGURE 1.

Two kelps, Nereocystis luetkeana (Mert.) Post. et Rupr. and Macrocystis integrifolia Bory, could be used in agricultural crop production because they are abundant and easily harvested.

The kelp N. luetkeana is by far the most abundant with an estimated annual standing crop of approximately 500,000 metric tonnes covering 11,600 ha (Foreman, 1984). This plant is an annual and its reproductive organs are located on lamina near the surface. Harvest of the standing crop is therefore restricted to one cutting in the fall after the plant has released its spores. The amount harvested can be no greater than 20% of the total stand, and harvests should be performed in 100 m cross-current widths so that unharvested plants can seed the harvested area (Foreman, 1984).

The kelp M. integrifolia (Figure 2) is much less abundant than N. luetkeana with an estimated annual standing crop of approximately 34,600 metric tonnes covering 2,300 ha (Coon, 1982). The plant has a perennial holdfast which secures it to a rock substrate. Seasonal stand establishment is not primarily by spores, as is the case with N. luetkeana, but from its perennial holdfast.

HARVESTED VEGETATIVE PORTION OF THE KELP

Macrocystis integrifolia

FIGURE 2.

Unlike N. luetkeana the reproductive organs or sporophylls of M. integrifolia are located near the base of the plant and are not removed during harvest. Because of these growth and developmental differences between the kelps, harvests of the established M. integrifolia stands are less restricted and several harvests of the same beds during a growing season are possible (Coon, 1983). It is because of the less restrictive harvesting strategies that M. integrifolia was selected as the kelp to investigate for its potential use in crop production as a soil amendment (Chapter 3) and crop foliar spray (Chapter 4).

2.2 Biology of the Kelp Macrocystis integrifolia

Three species of the genus Macrocystis are generally recognized in the world: M. pyrifera, M. augustifolia and M. integrifolia. Their distributions include coastal regions of Peru, Chile, Argentina, South Australia, New Zealand (South Island), South Africa and Antarctica. In North America, the genus occurs only on the Pacific Coast, with M. integrifolia extending from Kodiak Island in Alaska to the Monterey Peninsula, California. M. integrifolia is the only species of this genus on the coast of British Columbia (Bold and Wynne, 1978). The alga is restricted to

regions where only slight seasonal variations in seawater temperatures and salinity exist. These environmental restrictions prevent the growth of the alga in Johnston and Georgia Straits. Lower vertical distribution is normally limited to 10 m below mean zero tide and is often controlled by lack of appropriate substrate or by the upper grazing limit of the sea urchin Strongylocentrotus franciscanus (Druehl, 1978). Figure 3 depicts a major stand of M. integrifolia near Port Hardy, B.C.

The plant sporophyte (Figure 4) can exceed 33 m in length and 50 kg in weight. The basal portion (holdfast) of Macrocystis is perennial and capable of regenerating additional stipes each growing season. The blades (laminae) initially undergo longitudinal division and divide inwardly to give rise to the reproductive sporophylls. The outer blades continue to split giving rise to a procession of sterile vegetative blades. These blades eventually reach the top of the water column and then continue to split along the surface. Each of the vegetative blades is maintained at or near the water column surface by a gas filled pneumatocyst at the point where it attaches to the stipe. The blades can reach 0.40 m in length (Lobban, 1978b).

Macrocystis integrifolia KELP BED NEAR PORT HARDY, B.C.

FIGURE 3.

Macrocystis integrifolia IN THE WATER COLUMN

(after Whyte, 1978)

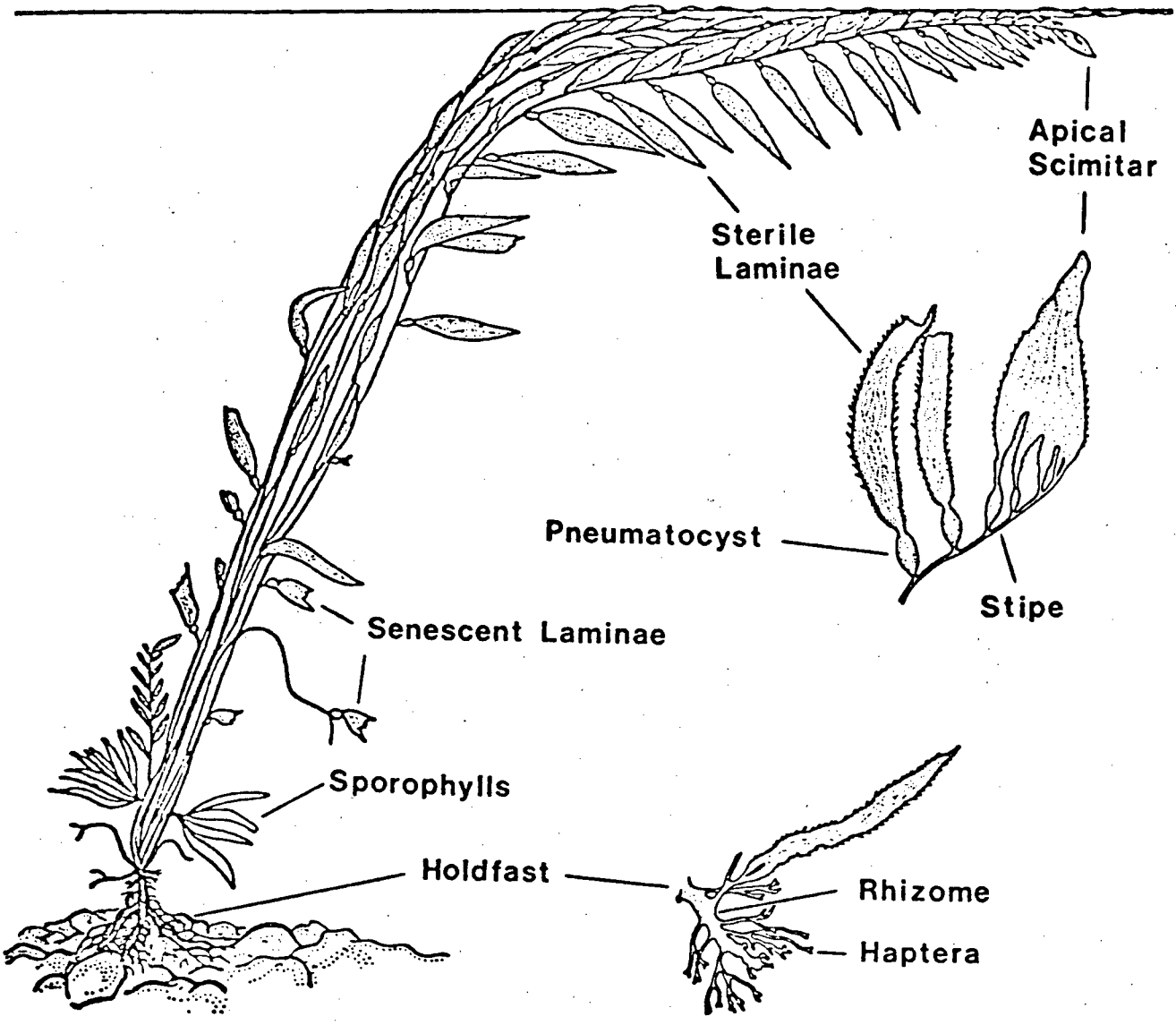


FIGURE 4.

The reproductive life cycle of Macrocystis, like many marine plants, is obscure and timing of the various reproductive stages is not well defined. The life cycle involves the release of motile zoospores from the mature sporangia of the sporophyte. These settle on the sea bottom and develop into microscopic male and female gametophytes. The flagellated spermatozoid of the male gametophyte fertilizes the egg in the oogonium of the female gametophyte, resulting in the formation of a zygote. The zygote then develops into the sporophyte or giant kelp previously described (Bold and Wynne, 1978). Sporophytic growth occurs from February to the end of October and the growth pattern is sigmoidal, with maximum growth occurring in the early spring. July to September tends to be the most active period for zoospore release. During the winter, many of the fronds become damaged and detached from the holdfast as a result of storms, therefore, a vast majority of the established canopy is no greater than 6 months in age (Lobban, 1978a and 1978b).

Smith et al. (1983) investigated the seasonal photosynthetic performance of M. integrifolia. Peak photosynthetic performance occurred from April to July and declined thereafter. Such trends in photosynthetic

performance were inversely correlated with ambient seawater temperature.

Rossel and Srivastava (1984) and Wheeler and Srivastava (1984) examined the seasonal variations of various chemical constituents of M. integrifolia over a two-year period (Table 2). Marked seasonal trends in ash, alginate, mannitol, B, N, P and K concentrations existed. N, P and K concentrations were high in winter and lower in summer with B having a reverse trend. The concentrations and ranges for Na, Sr, Fe, As, Al, Zn, Mn, Cu and Co are also presented in Table 2 and displayed no seasonal trends. The plant demonstrated an ability to concentrate the elements (in decreasing order) P, Fe, As, Al, Mn, Cu, K and B over ambient seawater levels. Leaching the plant tissue with water, acid or methanol suggested that the alkali metals Na and K are present primarily as inorganic salts while divalent Ca, Mg and Sr were bound to alginic acid. The ash content was at a minimum in the summer and a maximum during fall and early winter. Kelp mannitol and alginate vary seasonally and inversely to that of seasonal ash contents.

High levels of N and K in th kelp suggest that it could be an ideal soil amendment for the coastal or isolated island

TABLE 2. SEASONAL VARIATION OF CHEMICAL CONSTITUENTS OF *Macrocystis integrifolia* (APICAL 2 m)

(after Rossel and Srivastava, 1984 and Wheeler and Srivastava, 1984)

Chemical constituents:	[a] %						mg kg^{-1}
Month	Ash	Mannitol	Alginate	N	P	K	B
January	40.5	4.0	24.0	2.10	0.56	10	125
February	41.0	5.0	26.0	2.64	0.59	8	100
March	38.0	14.0	25.0	2.94	0.46	7	120
April	32.0	15.0	24.0	1.15	0.33	6	210
May	30.0	15.0	29.0	1.12	0.59	5	380
June	28.0	14.5	30.0	1.59	0.33	5	165
July	24.0	16.0	31.0	0.83	0.26	5	160
August	25.0	16.5	26.0	0.94	0.20	3	200
September	30.0	9.5	23.5	2.54	0.33	4	200
October	32.0	5.0	23.0	2.62	0.36	6	140
November	Not sampled						
December	42.0	2.0	22.0	2.26	0.50	8	110

[b] Other elements	Average	Range
Na %	3.55	2.2-4.5
Sr mg kg^{-1}	622	570-923
Fe mg kg^{-1}	127	37-923
As mg kg^{-1}	85	57-120
Al mg kg^{-1}	47	0-226
Zn mg kg^{-1}	23	5-112
Mn mg kg^{-1}	7	3-15
Cu mg kg^{-1}	5	0-15
Co mg kg^{-1}	< 2	--

[a] All measurements expressed on dry weight basis.

[b] No seasonal trends.

communities of British Columbia. Such a soil amendment may also be useful for farmers or gardeners who use organic supplements to inorganic fertilizers or on their own. The kelp's N and K concentrations are at their highest from the fall to late spring, therefore harvesting during this period would assure a kelp soil amendment with the highest mineral matter. The abundance of the kelp would also make it ideally suited for subsequent processing and use as a crop foliar spray.

2.3 Harvesting Strategy, Government Controls and Environmental and Social Implications

Aquaculture along the British Columbia coast is currently progressing from the research and development stage to a cottage industry. The B.C. Ministry of Environment, based on their ecological impact assessments, has formulated various laws and regulations with regard to harvesting and processing of marine plants as defined in the Fisheries Act, Chapter 137 and Fisheries Act Regulations 140/76.

Annual changes in standing crops of kelp are related to growth-limiting environmental conditions, primarily salinity

and temperature, some of which were discussed previously. Knowledge of long term fluctuations is important in planning resource allocations and industrial development. Such information would be used to assess the inventory of a standing crop prior to the harvest and setting of quotas (Coon, 1983).

The B.C. Ministry of Environment has investigated and developed a harvesting strategy for M. integrifolia which is based on 100% or better recovery of the standing crops after harvest (Coon, 1983). Areas which are harvested once a year should be cut 4.5 m above the seabed in May, June or July. Areas which are cut later than July produce higher yields, but do not usually obtain complete stand establishment by fall. M. integrifolia regenerates well when it is harvested several times over its growing season as long as cuts are made greater than 4.5 m above the seabed. Repeated harvests within the kelp bed (i.e. May and August or May, July and September cutting schedules) can be practiced. Multiple or single harvests which occur 1.5 or 3.0 m above the seabed result in poor regeneration and complete stand establishment by fall is seldom achieved (Coon, 1982 and 1983).

The environmental impacts of harvesting kelp on nine commercially valuable fish species which occur in or around kelp stands were examined by the B.C. Ministry of Environment. Preliminary findings have demonstrated that black cod, herring and chum, juvenile coho and sockeye salmon were found in equal or greater numbers in non-kelp habitats. Grey cod, ling cod and juvenile pink and larger coho salmon were found more frequently in the kelp habitat, but the Ministry has concluded that partial removal of the kelp canopy by harvesting would not result in a deteriorated habitat for these fish (Coon, 1983).

The Fisheries Act stipulates that marine plants are "common" property, owned and managed by the Province of British Columbia on behalf of the citizens of B.C. The regulatory power lies with the Ministry of the Environment and regulations provide for (after Coon, 1983):

1. license fees and reporting requirements for both harvesting and processing sectors,
2. payment of royalties (currently $1 per tonne) on harvested marine plants,
3. harvest licensing on the basis of species groups,
4. definition of harvest area,
5. setting of harvest quota for the species group in harvest area,

6. designation of approved harvest equipment,
7. designation of the manner in which harvesting may be carried out,
8. closing areas when necessary for conservation purposes.

A large scale kelp industry in B.C. has yet to be established, although harvesting of Macrocystis has been practised in California since 1910, with 150,000 tonnes harvested per annum. At present the B.C. Ministry of the Environment has set a maximum annual harvest quota of 5,000 wet tonnes. Until the environmental assessment of small scale harvesting ventures demonstrates that the kelp habitat and standing crop will not deteriorate with time the quota will not be increased (Coon, 1983).

Development of a kelp resource industry in B.C. has been slow as a result of political and legal uncertainties between the Provincial and Federal Governments and the Haida Indian Nation. An informal working agreement between the Federal Department of Fisheries and Oceans and the B.C. Ministry of the Environment provides for provincial licensing of commercial marine plant harvesting upon review by the federal counterpart. The Haida Nation, however, has

made formal claims of ownership to all of B.C. coastal marine resources, including the kelp resource. Despite these uncertainties, the provincial government invites kelp development proposals since aquacultural development is deemed essential to the progress of B.C. coastal communities (Coon, 1983).

CHAPTER THREE

THE KELP, *Macrocystis integrifolia*, AS A SOIL AMENDMENT

3.1 Effects of Kelp (*Macrocystis integrifolia*) on Soil Chemical Properties and Crop Responses

3.1.1. Introduction

Quantitative investigations into the use of fresh kelp as a soil amendment have been few. The objective of this investigation was to determine the immediate two year effects of a single application of fresh kelp, *Macrocystis integrifolia* Bory, applied to a fine-textured soil on crop growth and nutritional responses and soil chemical properties.

3.1.2 Materials and methods

On June 19, 1981 kelp (*M. integrifolia*) was harvested just offshore and south of Port Hardy, British Columbia (N latitude 50^{o} 43'; W longitude 127^{o} 20'). The kelp was cut one metre beneath the surface of the water with a mechanical harvester. In the rear of the harvester the kelp was chopped into pieces of less than 40 mm and dropped into a

barge below. The kelp was then placed in plastic-lined totes on the deck of a truck, covered and transported to the study site on Westham Island, B.C., part of the Fraser River delta (N latitude 49^{o} 05'; W longitude $123^{o}10'$).

Grab samples of kelp were taken from each of the six totes on the day of application and placed in zip-lock plastic bags. The bags were placed in an ice box, transported back to the laboratory and stored in the freezer at $-15^{o}C$. The kelp was thawed and then dried at $70^{o}C$ in a forced air oven to a constant weight for elemental analysis and moisture content determination.

The soil is classified as Westham SiCL (35% clay, 55% silt, 10% sand), Saline, Rego-Humic Gleysol (U.S. eq. Humic Haplaquept), and is formed in marine and deltaic alluvial deposits over sand (Luttmerding, 1981). Two days prior to kelp application, composite (16 cores) soil samples were taken from each plot. Soil samples were taken to a depth of 0.20 m, left to air dry and passed through a 2 mm sieve. The Westham 0-0.20 m layer had a bulk density of 1000 kg m^{-3}, pH (1:2 soil:water) of 5.0, an effective (pH 5.0) cation exchange capacity of 13.1 $cmol^{+}\ kg^{-1}$, total N content of 0.21%, Bray P1-extractable P of 69.9 mg kg^{-1}, exchangeable

K, Mg, Na, Ca and Mn concentrations of 0.81, 1.5, 0.21, 7.2 and 0.046 $cmol^{+}\ kg^{-1}$, respectively; Cl concentration of 120 $mg\ kg^{-1}$; electrical conductivity (EC) of 0.30 $dS\ m^{-1}$; NH_4-N concentration of 10.3 $mg\ kg^{-1}$ and NO_3-N concentration of 10.8 $mg\ kg^{-1}$. Methods of soil analysis are described below.

On 24 June, kelp was applied to plots at 0, 7.5, 15, 30, 60 and 120 $t\ ha^{-1}$ wet weight. All plots received a concurrent broadcast application of 200 $kg\ ha^{-1}$ of 0-45-0. The 4 m x 7 m plots were arranged in a randomized complete block design with four blocks. Eight days after the kelp was broadcast on the soil surface, composite soil samples were taken from the 0-0.20 m soil layer beneath the kelp from each of the 0, 60 and 120 $t\ ha^{-1}$ plots. Nine days after the kelp application the plots were disked to a depth of 0.15 m. Seven days after disking, field beans (Phaseolus vulgaris L. cv. Galamor) were inoculated (Rhizobium leguminosarum biovar phaseoli) and planted to a depth of 35 mm in 0.60 m wide rows along the length of each plot. In the second year (1982) the plots were moldboard ploughed in early April, disked, and inoculated (Rhizobium leguminosarum biovar leguminosarum) field peas (Pisum sativum L. cv. Coronet) planted on the 6 May (Day 1) to a depth of 35 mm. The plots received no additional mineral fertilizer or kelp

during the second year. Composite soil and bulk density samples (0-0.20 m) were taken from each plot five days prior to seeding of peas in the second year. Standard farm machinery was used for the ploughing, disking and planting.

Two row sub-plots 1 m long for measuring emergence and flowering were systematically established in the 0, 60 and 120 t ha^{-1} treatments 1 m in from a plot border. In each of the two years, emergence was determined by counting the number of plants at the two-leaf stage. The two leaf stage was defined as the time at which the two leaves were fully open and perpendicular to the embryonic stem axis. The emerged plants at the two leaf stage were marked and recorded on a map at approximately the same time of day. From the mapped sequence of emerging plants, ten plants were randomly selected for date of emergence and flowering counts during the first year. Flowering measurements were not made in the second year. During flowering (Day 45 in 1981 and Day 48 in 1982) a transect was laid along two rows in which ten tissue samples were collected randomly from each of the 0, 30, 60 and 120 t ha^{-1} plots in 1981 and the 0, 15, 30, 60 and 120 t ha^{-1} plots in 1982. The tissue samples taken at flowering in the first year consisted of the newest, fully open trifoliate (three leaves) and the whole plant in the

second year. At harvest, one kg combined leaf and stem and marketable (>80 mm) bean or pea pod samples were randomly collected from the harvested material from each plot for determination of dry matter yields and elemental composition.

Harvest occurred on 19 September, 1981 (Day 72) and 16 July, 1982 (Day 73). During harvest, sub-plots measuring 1.20 m x 2.00 m the first year and 2.00 m x 2.00 m the second year were established systematically in the centre of each plot. Fresh weights of the whole shoots and pods were obtained in the field. Grab samples of pea pods were taken in the second year and shucked to determine fresh pea yield and for subsequent dry weight determination. Composite soil samples (0-0.20 m) were taken from each of the plots on the harvest dates.

Crop samples were brought in from the field in paper bags and dried at 70^{o}C in a forced air oven. All plant material was ground in a stainless steel Wiley mill and passed through a 1 mm sieve prior to elemental analysis. A 1.000 g sample of plant tissue was digested (Parkinson and Allen, 1975) and K, Mn, Fe, Zn, Na, Cu, Pb, Al, Ca and Mg concentrations determined with the Perkin-Elmer 330 atomic

absorption spectrophotometer. Copper and Pb were determined on kelp material only. Nitrogen and P were determined colourimetrically using a Technicon Autoanalyzer II (Technicon, 1974a). Carbon was determined with a Leco Analyzer (Leco Manual, 1959) and kelp S with a Fisher S Analyzer Model 475 (Sulphur Instruction Manual). For S determination, approximately 50 mg of kelp plant tissue was placed in a resistance-type furnace held at 1350^{o}C in which S was quantitatively converted to SO_2. The SO_2 was absorbed and quantified using an automatic burette coupled with a microprocessor which calculated the % S (Sulphur Instruction Manual). Kelp B was determined using the azomethine-H method (Wolf, 1974). Bean Cl was determined with an Orion halide electrode model 94-17 chloride probe (Orion Instruction Manual) after refluxing 1.000 g of plant material in 50.0 mL of distilled water for 30 min., filtering throught a Whatman #42 and making to a 50 mL volume. All elemental concentrations are expressed on a dry weight basis. Elemental uptakes are calculated by multiplying elemental concentration by dry matter accumulation.

The exchangeable cations K, Mg, Ca, Mn and Na were extracted with 1 M NH_4OAc adjusted to pH 5.0 (Chapman,

1965b) with a subsequent CEC determination (Chapman, 1965a). Cations were determined by the Perkin-Elmer 330 atomic absorption unit with NH_4 concentration for CEC determination determined colourimetrically with the Technicon Autoanalyzer II (Technicon, 1974b). Total N was determined using the Kjeldahl distillation method (Bremner, 1965). Soil samples of 10.0 g were extracted with 100.0 mL of 2M KCl for NH_4-N and NO_3-N determination. Both NO_3-N and NH_4-N were determined colourimetrically, with NO_3-N using the cadmium reduction method coupled with a Technicon Autoanalyzer II (Technicon, 1977). A 2:1 (water:soil v/w) extract was used in pH determinations (Peech, 1965). Electrical conductivity (EC) and soluble Cl concentration were determined by shaking 25.0 g of soil with 50.0 mL of distilled water for 1 h, leaving it to stand overnight and filtering through a Whatman #42 filter paper. Supernatant Cl and EC were then determined with an Orion halide electrode - model 94-17 chloride probe (Orion Instruction Manual) with EC measurements made with a Radiometer Type CDM2c conductivity meter (Jackson, 1956). Available P was determined colourimetrically following extraction with 0.03M NH_4F in 0.025M HCl (Olsen and Deans, 1965). All quantitative measurements were based on air dry weight. Rainfall data was obtained from Environment Canada, Delta Ladner South

Weather Station.

Data were subjected to analysis of variance with kelp application trend effects partitioned into linear (R/L), quadratic (R/Q), cubic (R/C) and residual (R/R) or deviant (R/D) where applicable. Statistical significance was determined at the 5% level and coefficients of variation (CV) given.

3.1.3 Results

The 1981 and 1982 analysis of variance calculated mean square error (MSE), means and F-values for bean and pea crop growth and elemental concentrations and uptake responses and soil chemical properties are presented in Appendices 1 - 8.

The elemental composition of the Port Hardy kelp used in this investigation is presented in Table 3. During the first growing season the 120 t ha^{-1} application of fresh kelp significantly reduced emergence and flowering (Figure 5). The bean plants in plots which had received 120 t ha^{-1} of fresh kelp were darker green (visual observation) than plants in plots with other applications. During the first growing season fresh and dry combined leaf and stem,

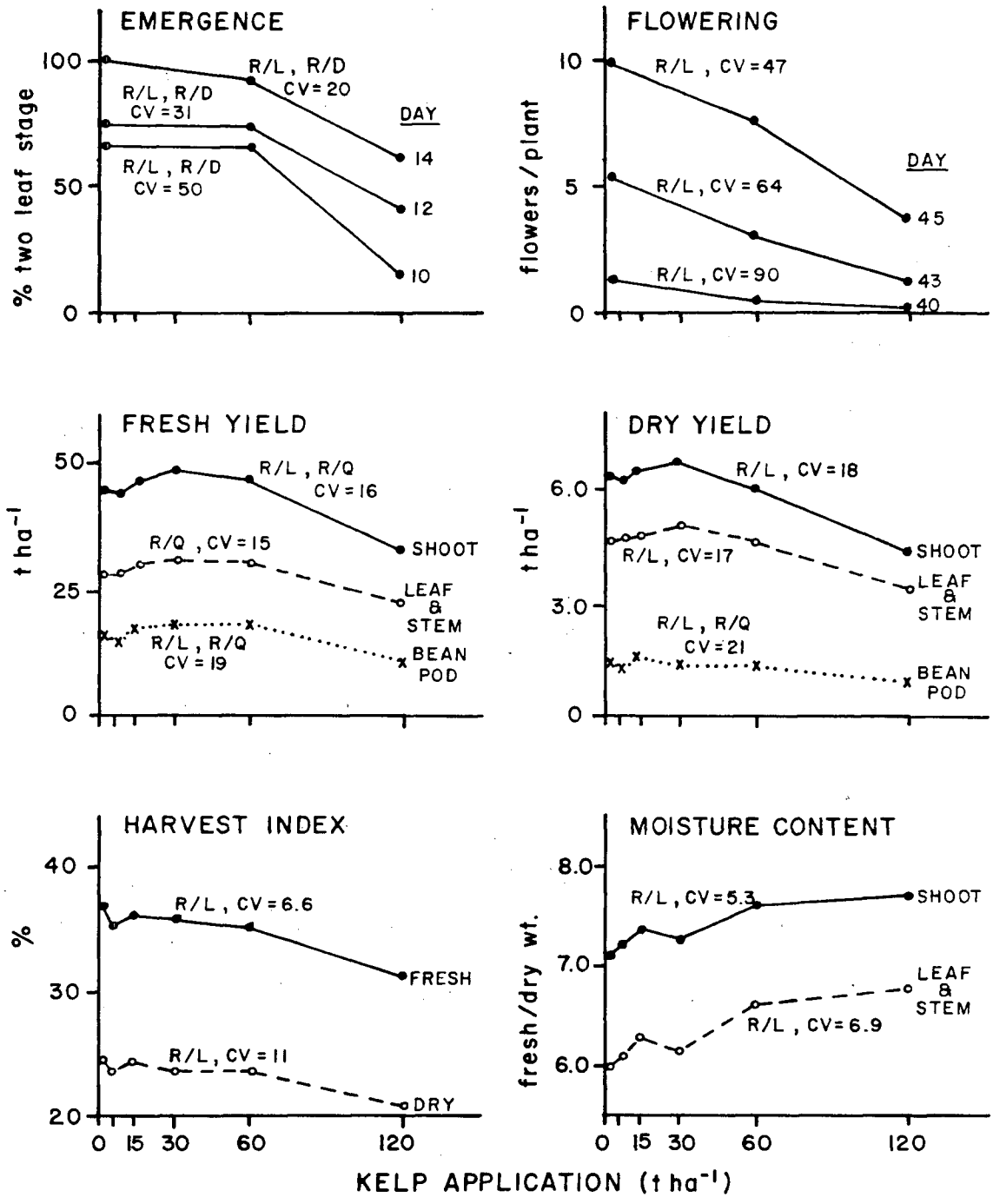
TABLE 3: KELP (*M. integrifolia*) ELEMENTAL CONCENTRATIONS

ELEMENT	PORT HARDY KELP DESCRIBED IN SECTION 3.1.2 [1]CONCENTRATION n=6	[2]CV	SOOKE KELP DESCRIBED IN SECTION 3.3.2 CONCENTRATION n=1
C %	27.3	7.00	27.2
N %	2.3	5.5	2.4
P %	0.4	2.8	0.41
K %	8.8	4.1	8.4
Ca %	1.21	8.59	1.12
Mg %	0.76	3.5	0.71
Na %	2.82	5.18	2.74
S %	1.0	20	0.90
Cl %	17	1.2	18.0
Fe mg kg^{-1}	442	34	360
Al mg kg^{-1}	392	38	330
B mg kg^{-1}	147	2.4	174
Zn mg kg^{-1}	12	42	10
Mn mg kg^{-1}	8	30	9
Cu mg kg^{-1}	<1		<1
Pb mg kg^{-1}	<1		<1

[1]Concentration expressed on dry weight of kelp: wet kelp contained 11% dry matter.

[2]Coefficent of variation

1981 BEAN GROWTH AND DEVELOPMENT



LEGEND: The effects of increasing soil applications of fresh kelp (M. integrifolia) on bean growth and development.

FIGURE 5.

marketable (>80 mm) bean pods, total shoot yields and harvest index (percentage of the plant weight which is marketable beans) had little response to increasing kelp applications through to 60 t ha^{-1} and were reduced with the 120 t ha^{-1} application. The shoot moisture content increased with increasing kelp application.

Increasing kelp applications resulted in significant increases in bean trifoliate concentrations of K, Cl, Na and Mn at flowering; combined bean leaf and stem K, Cl, Fe and Zn and bean pod Mn and Zn at harvest of the first growing season (Table 4).

At harvest of the first year combined bean leaf and stem uptake of K initially increased with increasing kelp applications through to 60 t ha^{-1} and then subsequently decreased, as did the combined leaf and stem dry matter yields, with the 120 t ha^{-1} kelp application (Table 5). Bean pod uptake of N, P, K, Ca, Mg, Fe and Zn (Table 5) followed closely that of bean pod and combined leaf and stem dry matter yields.

In the subsequent growing season increasing kelp

TABLE 4. 1981 BEAN ELEMENTAL CONCENTRATION.

Kelp Application (t ha^{-1}):	0	7.5	15	30	60	120	Significant Trend Effect	CV
Flowering (trifoliate):								
K (%)	3.3	a	a	3.2	3.7	3.8	R/L	11
Cl (%)	0.88	a	a	1.10	1.20	1.40	R/L	20
Na (mg kg^{-1})	140	a	a	160	180	210	R/L	25
Mn (mg kg^{-1})	35	a	a	54	47	66	R/L	36
Harvest (leaf & stem):								
K (%)	2.4	3.3	2.7	2.6	3.2	3.2	R/L;R/Q	15
Cl (%)	0.88	1.30	1.30	1.40	1.50	1.70	R/L	29
Fe (mg kg^{-1})	180	180	220	170	210	240	R/L	21
Zn (mg kg^{-1})	36	36	40	37	40	41	R/L	11
Harvest (bean pod):								
Mn (mg kg^{-1})	21	21	24	24	23	31	R/L	21
Zn (mg kg^{-1})	30	30	32	32	32	35	R/L	8.0

[a]Not sampled.

TABLE 5. 1981 BEAN ELEMENTAL UPTAKE.

Kelp Application (t ha^{-1}):	0	7.5	15	30	60	120	Significant Trend Effect	CV
Leaf & Stem:								
K (kg ha^{-1})	110	110	130	130	150	110	R/Q	18
Bean pod								
N (kg ha^{-1})	42.4	41.6	44.9	44.8	44.7	30.0	R/L;R/Q	22
P (kg ha^{-1})	5.4	5.4	5.6	5.8	5.4	3.4	R/L;R/Q	23
K (kg ha^{-1})	37	36	38	43	35	25	R/L;R/Q	27
Ca (kg ha^{-1})	5.8	5.7	5.8	6.8	5.5	3.6	R/L;R/Q	26
Mg (kg ha^{-1})	3.3	3.1	3.4	3.6	2.8	2.0	R/L	25
Fe (g ha^{-1})	150	110	120	130	120	84	R/L	30
Zn (g ha^{-1})	48	46	51	52	50	33	R/L;R/Q	22

applications had no residual effects on pea emergence, harvest index and fresh/dry weight ratios. The only growth variable to be significantly affected was combined dry pea leaf and stem yield, which decreased with the 120 t ha^{-1} kelp application (Table 6). Na concentration at flowering and Na and K concentrations at harvest were also increased in the combined pea leaf and stem foliage. The Na uptake initially increased with the 30 and 60 t ha^{-1} kelp applications and then subsequently decreased, as did the combined leaf and stem dry matter yields, with the 120 t ha^{-1} kelp application (Table 6).

Soil samples from 0-0.20 m taken eight days after the kelp application (Table 7, pre-seeding 1981) indicated that increasing applications of kelp resulted in significant linear increases in the soil EC, NO_3-N and soluble Cl and a decrease in soil pH. NH_4-N concentrations eight days after kelp application averaged 7.3 mg kg^{-1} and were not affected by kelp treatments. By harvest 1981, NH_4-N increased with increasing kelp applications. Increasing kelp applications continued to have an effect on soil NO_3-N, soluble Cl and EC until pre-seeding 1982 (Table 8).

The soil exchangeable K, Mg, Na and Mn at harvest 1981

TABLE 6. 1982 PEA GROWTH AND ELEMENTAL CONCENTRATION AND UPTAKE.

Kelp Application (t ha^{-1}):	0	7.5	15	30	60	120	Significant Trend Effect	CV
Growth Response:								
Dry leaf & stem (t ha^{-1})	3.29	3.11	3.26	3.25	3.16	2.71	R/L	12
Elemental Concentrations:								
Flowering (leaf & stem)								
Na (mg kg^{-1})	560	a	520	620	610	650	R/L	20
Harvest (leaf & stem);								
Na (mg kg^{-1})	900	850	920	1100	1100	1100	R/L;R/Q	16
K (%)	2.8	3.2	2.8	3.1	3.3	3.4	R/L	13
Elemental Uptakes:								
Harvest (leaf & stem);								
Na (kg ha^{-1})	3.0	2.7	3.0	3.7	3.5	3.1	R/Q	22

[a]Not sampled.

TABLE 7. 1981 SOIL CHEMICAL PROPERTIES.

Kelp Application (t ha^{-1}):	0	7.5	15	30	60	120	Significant Trend Effect	CV
Preseeding 1981:								
NO_3-N (mg kg^{-1})	31	a	a	a	50	78	R/L	43
pH (2:1 water:soil)	5.7	a	a	a	5.1	5.2	R/L	9.2
Soluble Cl (mg kg^{-1})	140	a	a	a	1000	1600	R/L	80
EC (dS m^{-1})	0.48	a	a	a	1.7	2.4	R/L	61
Harvest 1981:								
NO_3-N (mg kg^{-1})	19	21	22	31	32	31	R/L;R/Q	28
NH_4-N (mg kg^{-1})	3.7	4.4	4.0	4.1	3.9	6.7	R/L	38
pH (2:1 water:soil)	5.2	5.0	5.0	4.9	4.9	4.4	R/L	8.1
Soluble Cl (mg kg^{-1})	260	390	430	560	600	820	R/L	40
EC (dS m^{-1})	0.52	0.60	0.63	0.80	0.98	1.40	R/L	39
Exchangeables ($cmol^+$ kg^{-1});								
K	0.85	0.83	0.95	0.93	1.2	1.8	RL/R/Q	33
Na	0.30	0.36	0.35	0.50	0.61	0.87	R/L	43
Mg	1.5	1.5	1.5	1.5	1.6	1.7	R/L	27
Mn	0.045	0.044	0.048	0.048	0.055	0.060	R/L	26

[a]Not sampled.

TABLE 8. 1982 SOIL CHEMICAL PROPERTIES.

Kelp Application (t ha^{-1}):	0	7.5	15	30	60	120	Significant Trend Effect	CV
Preseeding 1982:								
NO_3-N (mg kg^{-1})	18	18	17	17	18	21	R/L	10
Soluble Cl (mg kg^{-1})	210	190	170	220	220	230	R/L	12
EC (dS m^{-1})	0.31	0.34	0.33	0.36	0.34	0.40	R/L	12
Exchangeables ($cmol^+$ kg^{-1});								
K	0.73	0.87	0.83	0.85	1.0	1.6	R/L;R/Q	33
Na	0.21	0.20	0.19	0.24	0.27	0.29	R/L	20
Mn	0.045	0.039	0.044	0.048	0.050	0.055	R/L	5.3
Harvest 1982:								
Exchangeables ($cmol^+$ kg^{-1});								
K	0.79	0.87	0.88	0.98	1.0	1.3	R/L	28
Na	0.26	0.22	0.21	0.29	0.31	0.36	R/L	23
Mn	0.042	0.036	0.040	0.043	0.046	0.048	R/L	19

increased linearly with increasing kelp applications (Table 7). Linear increases for exchangeable Mn, Na and K were recorded at pre-seeding and harvest 1982 (Table 8). Available soil P and exchangeable Ca were not influenced by kelp applications at any time with this soil. The soil pH at pre-seeding and harvest 1982 was not affected by kelp applications.

The site received 978 mm of precipitation from October 1981 to April (inclusive) 1982.

3.1.4 Discussion

The lack of any bean plant yield responses to increasing kelp applications, through to 60 t ha^{-1}, is probably related to the initially high fertility of the Westham soil. Eight days after application of kelp, M. integrifolia, sharp increases in soil water soluble salts (EC) and Cl and a decrease in pH were recorded. Many of the crop growth and nutritional responses were indicative of plants growing in soil of increasing salinity. According to Levitt (1980) both drought and salt stress cause plant dehydration and several mechanisms to tolerate these conditions have evolved. One mechanism is osmoregulation,

in which plant tissue K concentration is increased in an effort to maintain turgor. Another response of the plant to high internal salt concentrations is to dilute the salts with water, which increases the plant moisture content. According to Bhivare and Nimbalkar (1984), beans (P. vulgaris) showed an increased moisture content in response to salt stress. In this investigation, both crop K concentration and uptake and moisture contents increased as kelp additions increased soil levels of soluble salts (EC) and exchangeable K. Bean crop emergence, flowering, harvest index and yield responses were all reduced with 120 t ha^{-1} application of kelp. Maas and Hoffman (1977) have recorded similar growth effects with beans grown in salt solutions. Plants which had received the 120 t ha^{-1} application were very dark green in appearance and according to Hajrisuliha (1980) this is characteristic of Cl toxicity. Subsequent greenhouse experiments by the author (Section 3.3) support the hypothesis that many observed plant growth responses documented in this field investigation were salt induced.

The kelp Na concentration was 2.82%. Increasing kelp applications increased soil exchangeable Na and Na concentration of the bean trifoliate and combined pea leaf and stem plant tissue. Bean Na concentrations increased

much less than those of peas and no effects were recorded in either the bean leaf and stem or pod foliage at harvest. Beans have been reported to retain Na in the roots and basal portions of the stems (Jacoby, 1964) and to exude Na from their roots to avoid Na toxicity (Lessani and Marschner, 1978). This could explain the very low levels of Na in the combined bean leaf and stem and undetectable levels in the bean pod. In the second year, combined pea dry leaf and stem yields were reduced in response to the 120 t ha^{-1} applications of kelp. The increased combined leaf and stem Na concentrations with increasing kelp applications and subsequent decrease in shoot Na uptake with 120 t ha^{-1} kelp application suggest that Na toxicity may have occurred.

Bean foliar concentrations of Fe, Zn and Mn increased with increasing applications of kelp. Maas et al. (1972) have demonstrated a positive correlation between plant elemental concentration of Fe, Mn and Zn with high, salt-induced, osmotic potentials of the growth media. The increasing soluble salt (EC) with increasing kelp applications may have also caused the observed decline in soil pH and subsequent increases in the availability of micronutrients. The increases in foliar concentrations of Fe, Zn and Mn with the 120 t ha^{-1} kelp application may also

be related to its reduced bean dry matter production. Future investigations should make an effort to determine both B and Mo foliar concentrations. The kelp did supply a significant amount of B to the soil and the subsequent increase in soil acidity with large kelp applications could also affect the availability of Mo.

Increases in soil exchangeable Mn and Mn concentrations in the bean trifoliate and pods and pea pods grown on the Westham soil were observed. There was also an increase in pea pod Mn uptake with increasing kelp application in the second year. Neutral, Cl containing salts, such as KCl and NaCl, can cause increased Mn concentrations of plants and levels of Mn in acidic soils (Tisdale et al., 1985). According to Krishnamurti and Huang (1987) KCl applications to various classes of temperate and tropical soils can greatly increase the release and availability of Mn. Increased Mn release by KCl were attributed to the complexing of Mn^{+2} by Cl^{-} to form $MnCl^{+}$. Francki (1960a, 1960b, and 1964) also reported large increases in soil exchangeable Mn and Mn concentration in tomato plants associated with large applications of the algae Pachymenia himantophora and Durvillea antarctica. Francki attributed reduced yields to Mn toxicity and N immobilization. The C/N

ratios of these algae were high, but their Mn concentration was <5 mg kg^{-1}, which is lower than the kelp used in this investigation. Francki claimed that the addition of kelp caused soil particles to disperse and the soil to become waterlogged. Prolonged waterlogging can decrease the soil redox potential and increase the concentration of the plant available Mn^{2+} form (Bohn et al, 1979). Francki made no reference to salts as a cause of reduced yields or increased soil levels of Mn, although K, Na and Cl concentrations in the algae were high.

The use of the fresh kelp, M. integrifolia, as a soil amendment rapidly increased the soil supply of available N. Eight days after the kelp was applied, NO_3-N concentrations of the soil underlying the yet unincorporated fresh kelp increased linearly and sharply with increasing applications. The low C/N ratio (11.9) of the kelp probably resulted in rapid decomposition and net mineralization of approximately 30% of the kelp's total N. According to Whyte (1981), M. integrifolia lost 23% of its total N after one fresh water washing and 31% after four. Whyte concluded that N may be present in the kelp as NO_3-N or low molecular weight polymeric N forms which readily leach.

Caiozzi et al. (1968) reported increases in available P with the use of kelp as a soil amendment to calcareous soils. In this investigation, kelp P concentration was low (0.40%) and increasing kelp applications had no measurable effect on the available soil P or bean shoot uptake up to 60 t ha^{-1}. A slight decline in shoot P uptake, in response to declining yields, was recorded with the 120 t ha^{-1} kelp application. The fact that no positive effects were measured may be related to the high levels of available P (69 mg Kg^{-1}) of the Westham soil.

The kelp M. integrifolia, used as a soil amendment in this investigation, increased soil N, K, Cl, Mn and Mg which may be beneficial for crop production. Increasing levels of soil soluble salts (EC), Cl and exchangeable Na with increasing kelp applications could eventually inhibit the growth of salt sensitive crops. Caution is in order when soils are amended with large quantities of kelp immediately prior to seeding. In addition, residual effects of kelp-derived soluble salts may be higher in other areas than in coastal British Columbia, where high winter rainfall consistently leaches salts from soils with adequate internal drainage. Economics would probably limit large-scale domestic use of this kelp as a soil amendment to more

isolated island communities such as the Queen Charlotte Islands or to Vancouver Island regions where the close proximity to the kelp resource could make it viable to harvest and transport to the farm. Alternately the kelp could be dried and packaged as an organic fertilizer supplement for use in greenhouses and where organic farming is practiced or on household plants, urban gardens, lawns, golf courses and nurseries.

3.1.5 Conclusions

Many of the soil and crop growth and nutritional responses to increasing applications of fresh kelp, M. integrifolia, were indicative of increasing soil soluble salts. Soil NO_3-N, K, Mn, Na, Cl and EC increased with the quantity of kelp applied. Bean crop Cl and K concentration and uptake and moisture contents increased as kelp additions increased. In the first season bean crop growth responses such as yields, emergence, harvest index and flowering were not reduced until 120 t ha^{-1} of kelp was applied to the soil. Pea growth and nutritional responses was also adversely effected with the 120 t ha^{-1} kelp application in the second year. Na concentration at flowering and Na and K concentrations at harvest increased in the combined pea leaf

and stem foliage. This kelp had a low C/N ratio (11.9) and is comparable to high quality barnyard manure in N concentration (2.3%), of which approximately 30% was readily available as NO_3-N soon after application. This kelp is one of the most concentrated organic sources of K, containing 8.8%. The kelp is low in P (0.4% P) and supplementary phosphate fertilization may be necessary on P deficient soils. Farm use of greater than 60 t ha^{-1} of fresh M. integrifolia as a soil amendment may reduce the yields of salt-sensitive crops seeded immediately after kelp application.

3.2 The Short-Term Effects of Fresh Kelp (*Macrocystis integrifolia*) on Physical Properties of a Fine-Textured Soil

3.2.1 Introduction

In a field plot investigation fresh kelp (*M. integrifolia*) was broadcast and incorporated into a silty clay loam soil in the Lower Fraser Valley of British Columbia (see Section 3.1). Whyte (1978) has shown that *M. integrifolia* contains a high concentration of polysaccharides, including cellulose, fucoidans and algins. Long-chain molecules, such as polysaccharides, are important in the formation of soil aggregates and the incorporation of an organic soil amendment containing polysaccharides may have beneficial effects on soil structure (Hillel, 1980).

Strongly-aggregated soils generally have a high volume of air-filled pores which have the capacity to drain quickly and to remain air filled for much of the time. Low soil aeration will limit the rate of diffusion of gases into and out of the soil because a greater proportion of the gases must be exchanged through the water phase, which has a relatively lower rate of gas diffusion. Adequate root and

microorganism respiration requires that the soil be aerated so that oxygen does not become deficient and to prevent an excess of carbon dioxide from developing in the root zone. Moreover, soil aeration has become a limiting factor to crop productivity as soil nutrient and water limitations have been reduced with increased use of fertilizers and irrigation (Hillel, 1980).

The objective of this study was to assess the structural effects of the kelp, M. integrifolia, soil amendment on a fine-textured soil. Modification to soil structure over two years was evaluated by measuring bulk and particle density, and aeration and total porosity.

3.2.2 Materials and methods

The method of kelp harvest and soil incorporation, soil and plot description and types of crops used in the 1981 and 1982 field trials are described in Section 3.1.2.

At flowering (Day 45 in 1981 and Day 48 in 1982) a line transect, with three randomly selected positions along it, was established along each length of the 0, 30, 60 and 120 t ha^{-1} treated plots, 1.5 m in from the plot border. At each

point along the transect a 75 mm diameter core (76 mm in length) sub-sample were taken from a depth of 50 mm into the plough zone (0-0.20 m). Each core was excavated, placed in a plastic bag, put into a cardboard ice-cream container and transported back to the laboratory in an icebox. All 48 core samples were then placed in the cooler at 10^{o}C until analysis. Total porosity was determined by suspending the cores on a metal grate and slowly (24 h) allowing the water level to rise to the top of the core, after which they were quickly weighed. The saturated cores were then placed upon a tension table and allowed to drain for 12 h at a water potential of -6.0 kPa and weighed. The weight loss of the cores between saturation and after being freely drained was used to determine the soil aeration (Vomocil,1965). Bulk density was determined by the core method described by Blake (1965). The weight difference between that of the oven-dried and water saturated core (0 kPa) was used to calculate the total porosity. Particle density was calculated by using the total porosity and bulk density for each core. Rainfall
data were obtained from Environment Canada, Delta Ladner South Weather Station.

Aeration and total porosity measurements were made

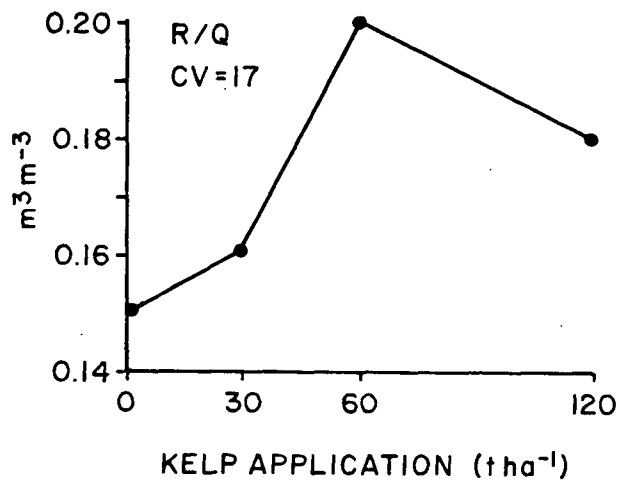
simultaneously on samples from within each block of the field experiment. All data were subjected to analysis of variance with kelp application effects partitioned into linear (R/L), quadratic (R/Q) and deviant (R/D) components. Statistical significance was determined at the 5% level and coefficient of variations (CV) given.

3.2.3 Results

The analysis of variance, calculated mean square terms, means and F-values for all soil structure variables are presented in Appendix 9.

Increasing applications of kelp had no significant effect on the bulk and particle density or total porosity of the soil over two years. The 1981 mean bulk and particle density and total porosity were 981 kg m^{-3}, 2430 kg m^{-3} and 0.597 m^3 m^{-3} respectively, whereas in 1982 they were 915 kg m^{-3}, 2470 kg m^{-3} and 0.630 m^3 m^{-3} respectively. The 1981 aeration porosity (Figure 6) increased significally with kelp applications up to the 60 t ha^{-1} and then decreased with the 120 t ha^{-1} application. The mean soil aeration of the soil in the second year was 0.22 m^3 m^{-3}.

SOIL AERATION



LEGEND: The effects of soil incorporated fresh kelp (M. integrifolia) applications on soil aeration porosity.

FIGURE 6.

3.2.4 Discussion

The effect of kelp on aeration may be related to its chemical composition. This kelp has a high content of polysaccharides. Two of these are algins at 18% (dry weight basis) and fucoidans at 3.3% (Whyte, 1978). These are extremely sticky and viscous. Such constituents may act as "cementing agents" and reduce the slaking of aggregates caused by the repeated wetting and drying of the soil (Hillel, 1980). Increased aggregate stability following kelp application could have reduced the infilling of interaggregate pores by crumbling aggregates. Such a reduction of the soil aeration could result in increased water-filled pores and water retention. A possible explanation for a lack of a treatment effect on soil aeration in the second year may be related to the different weather conditions prevalent during the two years. In 1981, the total rainfall from time of kelp application (June 24) until core sampling (August 22) was 69 mm. In the subsequent year (1982), the cumulative rainfall from disking (May 4) until core sampling (June 23) was only 16 mm. The lower rainfall of the second year could explain the relatively higher aeration and total porosity and lower bulk density as aggregate slaking may have been minimal.

The reduction in soil aeration porosity associated with the 120 t ha^{-1} kelp application may be related to the high level of Na and K salts associated with the kelp. The 120 t ha^{-1} kelp application supplied a total of 1160 and 373 kg ha^{-1} of K and Na, respectively. This quantity of monovalent cations could have caused the aggregates to slake or disperse more readily upon wetting, with a subsequent filling of aeration pores and an increase in interstitial water (Hillel, 1980). Such an effect of kelp-derived salts on the soil structure needs to be investigated.

3.3 Induced Salt Toxicity to Beans with Kelp (*Macrocystis integrifolia*) Soil Amendments

3.3.1 Introduction

A field investigation conducted (Section 3.1) in the Lower Fraser Valley, British Columbia, has shown reduced emergence, flowering and yields of beans (*P. vulgaris*) with an application of 120 t ha^{-1} of fresh kelp (*M. integrifolia*). Plant inhibition associated with this kelp application may have been due to nutrient immobilization, unknown phytotoxins and/or high salt concentrations. Nutrient availability (Jansson, 1971) or phytotoxins (Patrick, 1971) can have an inhibitory effect on plant emergence, germination and development. Levels of phytotoxins and nutrient availability may vary with incubation period as the kelp decomposes. Thus, incubating kelp treated soil for increasing lengths of time prior to seeding could alter emergence, growth and development of plants.

The objectives of this study were (a) to determine the effects on soil chemical properties and the growth of beans (*P. vulgaris*) when kelp (*M. integrifolia*) is applied in

increasing quantities and incubation periods prior to seeding, and (b) to evaluate the effects of subsequent leaching on the response of beans to different kelp applications.

3.3.2 Materials and Methods

Kelp (M. integrifolia) was harvested offshore from Sooke, British Columbia (N latitude 48°15'; W longitude 123°45'). The kelp was placed in zip-lock plastic bags and transported in an icebox back to the laboratory in Vancouver. The elemental composition of the Sooke kelp is presented in Table 3. Methods of elemental analysis are the same as those described in Section 3.1.2. Twelve hours after harvest the kelp was cut into pieces less than 40 mm, weighed into appropriate measures for each of the pots, placed in zip-lock plastic bags and kept frozen at -70°C until 24 h prior to mixing with the soil.

A bulk soil sample was removed from the 0-0.20 m zone of the plough layer of the Westham soil described in Section 3.1.2. Three bulk density core samples were taken from the immediate area and dried in a forced air oven at 105°C for 48 h for bulk density determination (Blake, 1965). Sub-

samples of the bulk soil were similarly dried to determine moisture content. Field-moist soil equivalent to 2.0 kg of dry soil was added to 2.3 L plastic pots achieving a bulk density of 1000 kg m^{-3} and soil moisture maintained at approximately -33 to -36 kPa throughout the experiment by watering daily. Each pot was amended by mixing into the soil applications equivalent to 200 kg ha^{-1} of 0-45-0 and 0, 15, 60 or 120 t ha^{-1} of wet kelp using the field bulk density of 1000 kg m^{-3} for the 0-0.20 m depth.

Experiment I: The four kelp applications were established in factorial combination with subsequent incubation periods of 1, 3 or 5 weeks prior seeding. Six replicates of each treatment were placed in a greenhouse in a completely randomized design. One day prior to seeding, soil cores were taken to a depth of 50 mm to give 40 g of soil for pH, Cl and electrical conductivity (EC) determination. Bean (*P. vulgaris* cv. Galamor) seeds were wetted and inoculated (*Rhizobium leguminosarum* biovar *phaseoli*) just prior to sowing three seeds per pot at a depth of 40 mm. Incubation periods were timed so that all pots were sown at the same time. The seed, phosphate fertilizer, inoculant, kelp and soil used in this experiment were the same as those used in a companion field plot investigation (Section 3.1).

Emergence was assessed each day by counting the number of plants at the two-leaf stage in each of the pots. The two-leaf stage was defined as the time at which the two leaves were fully open and perpendicular to the embryonic stem axis. After full emergence each pot was selectively thinned to two plants per pot. At harvest (Day 74) bean plants were clipped at the soil surface and weighed immediately. The beans were then removed and weighed. The plant material was then placed in paper bags, dried at 70^{o}C in a forced air oven to a constant weight and weighed immediately for moisture determination.

One day after harvest, soil cores weighing approximately 100 g were composited from each of the pots receiving 0, 60 and 120 t ha^{-1} applications of kelp. A 10.0 g sub-sample for NH_4-N and NO_3-N analysis was then taken, with the rest of the soil returned to the pots. Pots were at field capacity (-33 kPa) at the time of sampling.

Experiment II: Prior to the commencement of this experiment three of the six replicates from each of the three incubation periods for each kelp application (excluding the

15 t ha^{-1} application) treatment of Experiment I were randomly assigned to the leached and the remaining three to the unleached treatments, giving nine replications for each of the remaining applications; 0, 60 and 120 t ha^{-1}. Prior to leaching the soil both the leached and unleached treatments were tested for homogeneity of plant emergence (two-leaf stage) and soil Cl concentrations, EC and pH using the methods described in Experiment I. The only significant difference (t-test) between the two groups was that the pots to be leached had a slightly higher EC (1.44 vs 1.24 dS m^{-1}).

The soil in each pot was thoroughly tilled, after which the leached pot received a volume of tap water equal to twice its total porosity of 0.58 m^3 m^{-3} (assuming a soil particle density of 2650 kg m^{-3}). The leached soils took three weeks to return to field capacity, and the unleached soils were maintained at field capacity during this period. The soil was subsequently tilled and allowed to equilibriate for one week. The soils were then sampled as described for Experiment I and analyzed for pH, EC and Cl. The following day, eight bean seeds were sown to a depth of 40 mm and the emergence to the two leaf stage measured as previously described. Once the plants in all treatments had reached

the two leaf stage, they were thinned to two plants per pot. At harvest (Day 41) plant weights and moisture contents and soil NH_4-N and NO_3-N concentrations were determined.

Soil pH, EC, Cl, NH_4-N and NO_3-N were determined using those methods described in Section 3.1.2. Soil temperatures were measured with silicon diodes (Hinshaw and Fritschen, 1970) placed vertically at the approximate centre of three pots receiving 0 and three receiving the 120 t ha^{-1} kelp application.

All data were subjected to analysis of variance. In Experiment I, application effects included linear (R/L) and quadratic (R/Q) or deviant (R/D), where applicable, with incubation effects partitioned into linear (INC/L) and deviant (INC/D). Interactions between application and incubation included INC/L*R/L, INC/L*R/Q, INC/L*R/D, INC/D*R/L, INC/D*R/Q and INC/D*R/D. In Experiment II, application effects were partitioned into linear (R/L) and deviant (R/D) with leaching (LCH) by application interactions including R/L*LCH and R/D*LCH. Statistical significance was determined at the 5% level and coefficients of variation (CV) given.

3.3.3 Results

The analysis of variance, calculated mean square errors, means and F-values for curvilinear and treatment effects upon the growth and soil chemical variables of Experiments I and II are presented in Appendices 10 - 13.

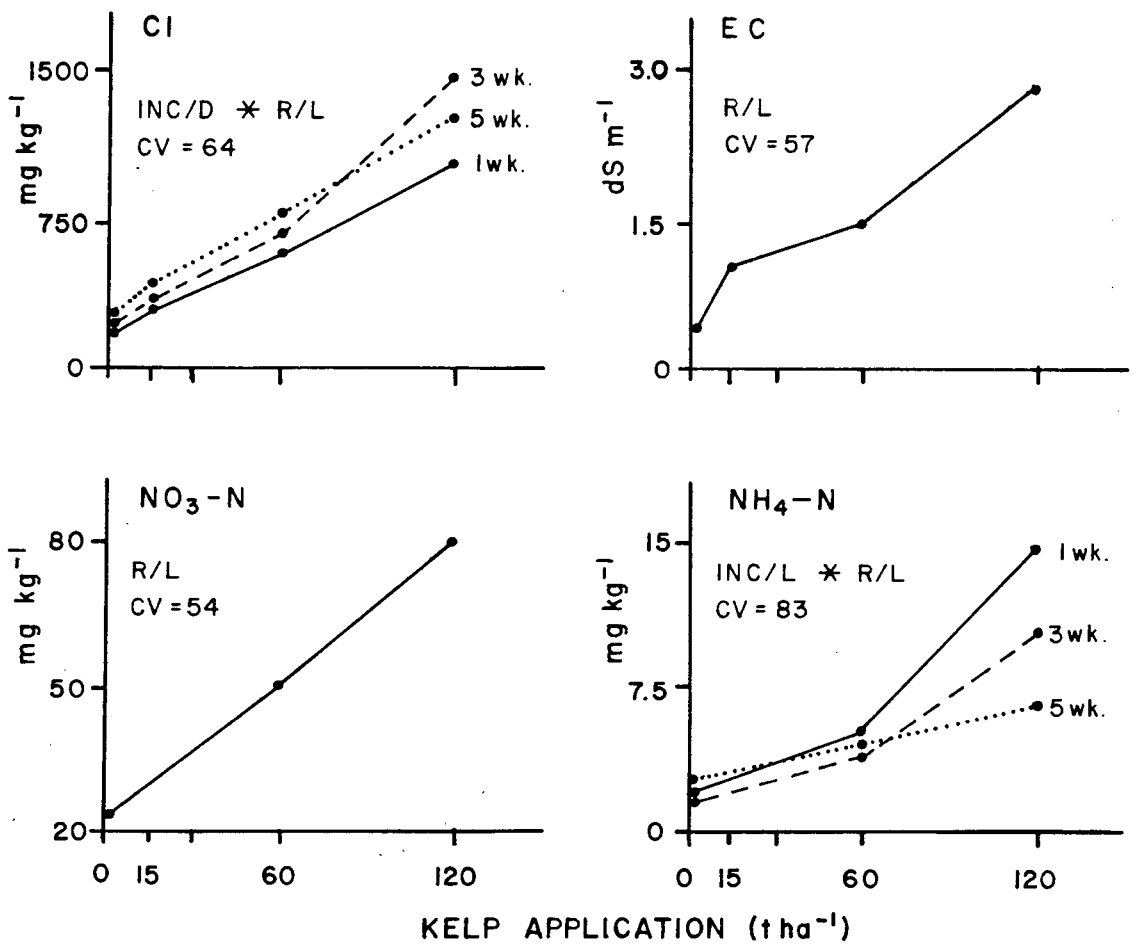
The daily means of ambient relative humidity for Experiment I and Experiment II were 75% and 65%, respectively. Average daily maximum temperatures for Experiment I and for Experiment II were 26^{o}C and 33^{o}C, respectively. Nightly minimum temperatures were 18^{o}C for both experiments. Soil temperatures followed ambient temperatures closely, but on average were 1-2^{o}C below peak ambient temperatures.

Experiment I: Soil EC and Cl concentrations increased with increasing quantities of kelp applied (Figure 7). Incubation period had no effect on EC, however, soil Cl concentrations were significantly higher following the three and five week periods than the one week incubation period. Incubation had no significant effect upon soil NO_3-N but incubation did affect soil NH_4-N concentrations with NH_4-N levels for the 120 t ha^{-1} kelp application decreasing with

EXPERIMENT I

SOIL CHEMICAL EFFECTS

(Application * Incubation)



LEGEND: The effects of soil incorporated fresh kelp (M. integrifolia) applications and varying incubation periods (1, 3 and 5 weeks) of kelp in the soil on soil chemical properties.

FIGURE 7.

increasing incubation period (Figure 7). Soil NO_3-N and NH_4-N concentrations increased with increasing kelp additions.

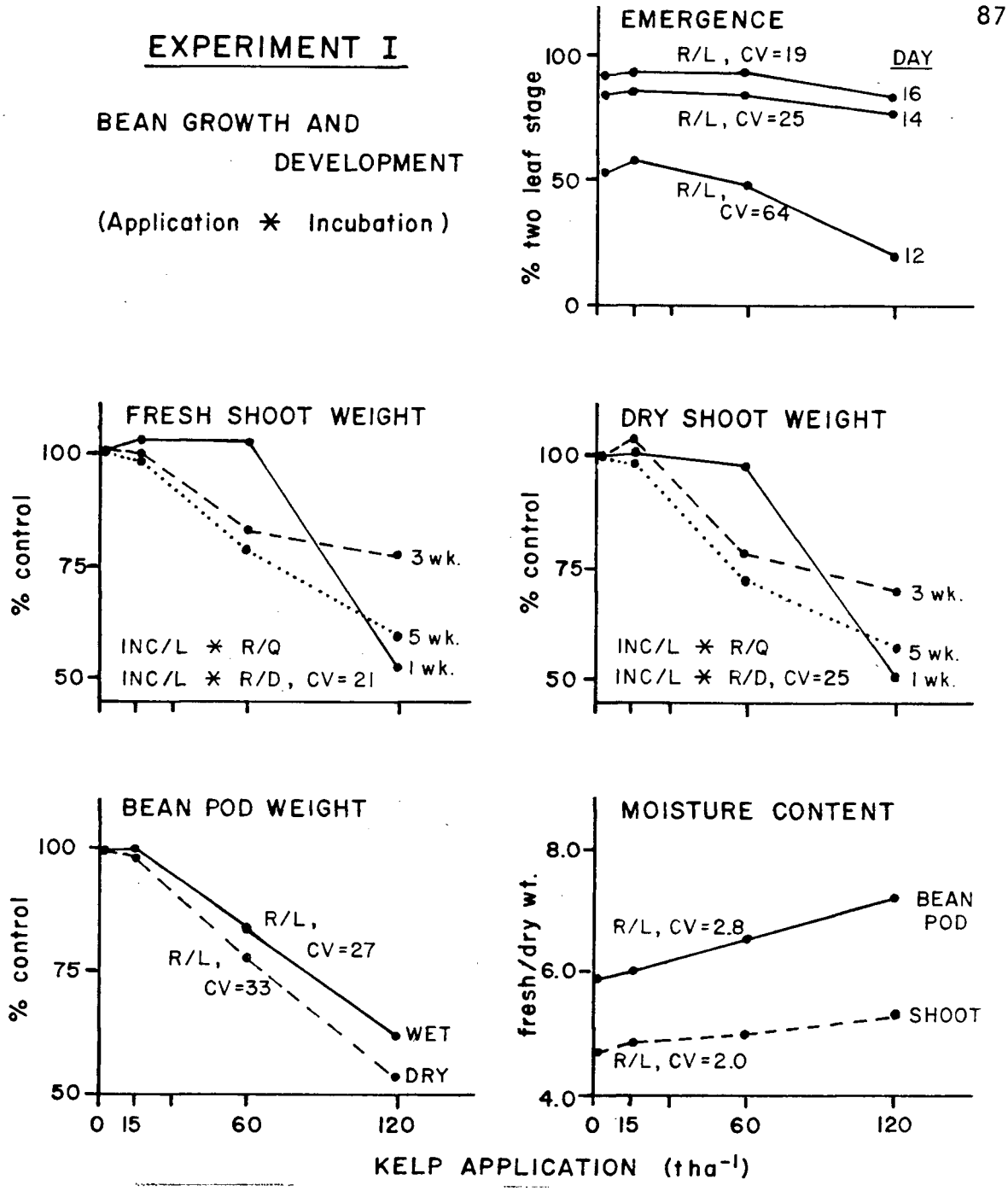
Plant emergence between days 12 to 16 was not affected by incubation period, but was reduced with the 120 t ha^{-1} kelp application (Figure 8). The leaves of plants receiving the 60 and 120 t ha^{-1} applications were smaller and darker green in colour at the two leaf stage than in the control and the 15 t ha^{-1} application. The symptoms were most pronounced at the 120 t ha^{-1} addition. Incubation period had no effect on bean yields, but bean yields were reduced with both the 60 and 120 t ha^{-1} kelp applications. Shoot responses to incubation period were small in comparison to the effect of increasing kelp applications. A reduction in shoot yields with the one week incubation occurred with the 120 t ha^{-1} application, whereas both the 60 and 120 t ha^{-1} applications, when incubated for three and five week periods, reduced yields. The moisture contents of the shoot and beans (fresh weight/dry weight ratios) was also increased with increasing kelp applications, while incubation period had no effect.

Experiment II: Soil samples taken after leaching and one day prior to seeding decreased in pH and increased in EC and

EXPERIMENT I

BEAN GROWTH AND DEVELOPMENT

(Application * Incubation)



LEGEND: The effects of soil incorporated fresh kelp (M. integrifolia) applications and varying incubation periods (1, 3 and 5 weeks) of kelp in the soil prior to seeding on bean growth and development.

FIGURE 8.

Cl concentration with increasing quantities of kelp added (Figure 9). The leached soils had higher soil pH, lower EC and Cl concentrations in comparison to soils which were not leached.

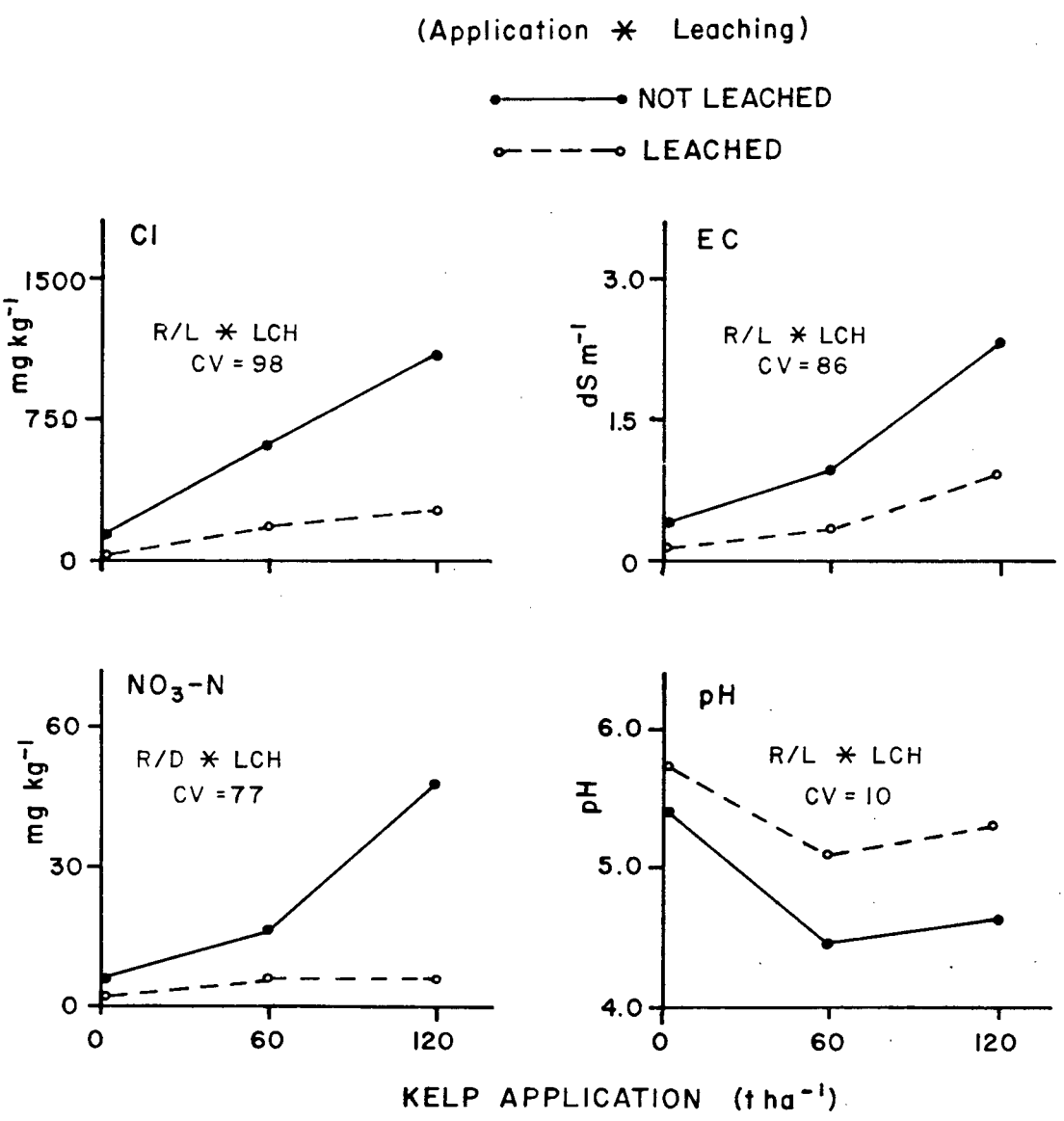
Plant emergence was greater with the leached soil as compared to unleached soils (Figures 10 and 11). The leaf symptoms observed in Experiment I were again evident with beans grown on soils which had not been leached. Plant leaves from soils which had been leached became chlorotic by flowering (Day 41) at which time the experiment was terminated.

Increasing kelp applications increased the fresh weight yields in leached soils but yields were reduced in unleached soils (Figure 10). Shoot dry matter yields followed similar but less pronounced trends. The plants grown on leached soils had a lower shoot moisture content than those grown on unleached soils, and in both groups of soils shoot moisture content was increased with increasing applications of kelp (Figure 10).

Soil samples taken at harvest (Day 41) from unleached pots increased in NO_3-N concentration with increasing kelp amendments (Figure 9). The leached soils had less NO_3-N

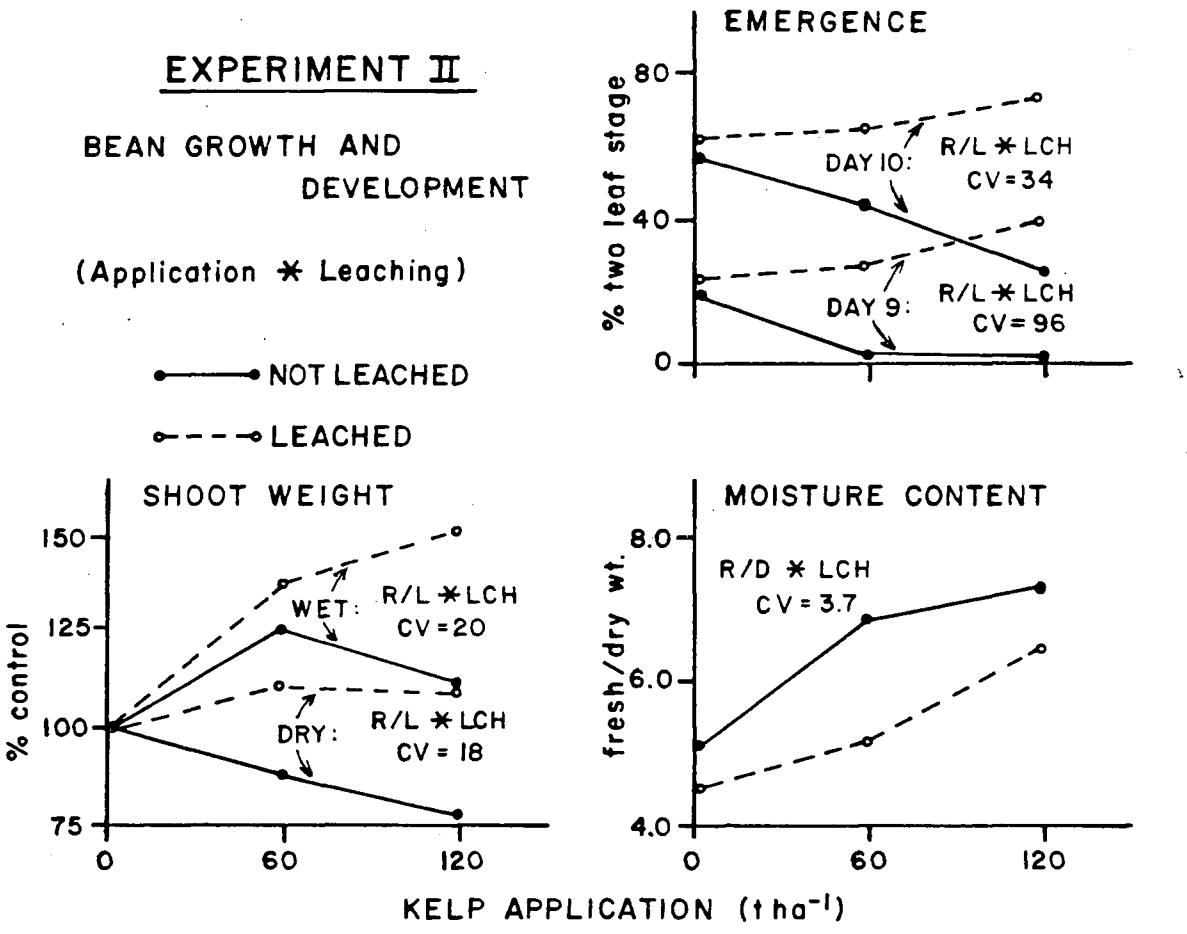
EXPERIMENT II

SOIL CHEMICAL EFFECTS



LEGEND: The effects of soil incorporated fresh kelp (M. integrifolia) applications and soil water leaching (leached and not leached) on soil chemical properties.

FIGURE 9

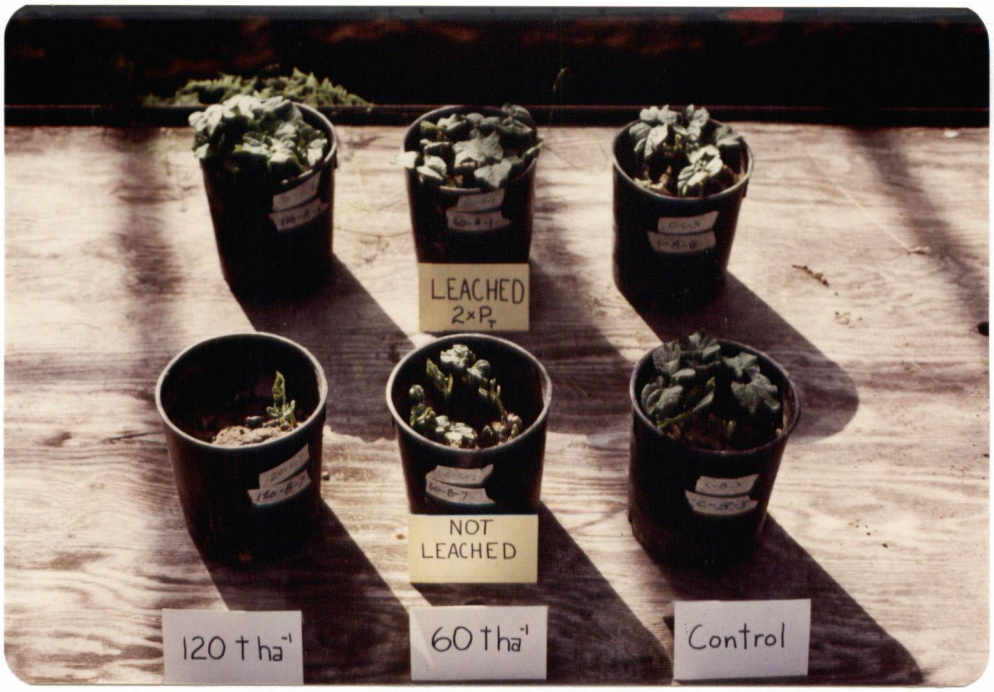


LEGEND: The effects of soil incorporated fresh kelp (M. integrifolia) applications and soil water leaching (leached and not leached) on bean growth and development.

FIGURE 10.

THE EFFECTS OF SOIL LEACHING ON BEAN EMERGENCE

(DAY 10)



LEGEND: Fresh kelp (M. integrifolia) applications to the soil are as indicated across the front (Control = 0 t ha^{-1} kelp application). The rear row of pots were leached with a volume of water equal to twice its total porosity ($2xP_T$) while the front row of pots were not leached.

FIGURE 11.

than the non-leached soils and no NO_3-N increases occurred with increasing kelp applications. The effectiveness of symbiotic N fixation was not evaluated.

3.3.4 Discussion

In this investigation (Experiment I) bean plant response to the quantity of kelp applied was significantly influenced by the length of time the kelp had incubated in the soil prior to seeding. The one week incubation greatly reduced shoot yields with the 120 t ha^{-1} application, while the three and five week incubation periods reduced yields with both the 60 and 120 t ha^{-1} kelp application. These results suggest that concurrent with increasing quantities of kelp, another unknown growth inhibiting mechanism may be implicated in reducing shoot yields. The apparent lag time in the phytotoxic response with the one week incubation (60 t ha^{-1} application) may be related to the rate of salt diffusion or biotic release of toxins. The dominant influence on bean pod growth, however, was related to quantities of kelp applied, since no significant incubation interaction was recorded with this variable.

The reduced bean emergence and yields experienced in

this investigation appeared to be related to concurrent increases in soil soluble salts and Cl concentrations. According to Hajrisuliha (1980) bean plants experiencing Cl toxicity have smaller leaves and are darker in colour. Rao (1980) reported that salt stress causes physiological changes in early seedling growth (second leaf stage) of Phaseolus radiatus. The translocation of reserve food products and the activity of enzymes responsible for metabolization of food reserves in the cotyledon were reduced, resulting in stunted growth and reduced emergence of seedlings. The same growth symptoms were observed in Experiments I and II (not leached soils) with the 120 t ha^{-1} kelp application and support the hypothesis that the reduced emergence and yields experienced with increasing kelp applications are related to increases in soil soluble salts.

Experiment II demonstrated that leaching soluble salts (EC) from the soil removed the kelp related inhibition of emergence at the 120 t ha^{-1} application. The leaching also removed much of the soil NO_3-N and the plants appeared N-deficient at flowering. Visual observations indicated poor nodulation for all treatments, hence the rapid response to reduced soil mineral N. Shoot dry weights at flowering were slightly increased by increasing kelp application in leached

soils but were reduced in unleached soils. Shoot moisture contents were increased by increasing kelp application and were lower in plants grown on leached soils. Shoot moisture contents probably reflected a water dilution response to internal plant salt accumulation. Levitt (1980) discusses this phenomenon as a strategy in which plants tolerate soil salt stress. Leaching the soil also reduced the soil acidity, which implies that some of the measured soil acidity may have been salt induced.

It would be incorrect to extrapolate all the results of this greenhouse pot study directly to a field situation. Under field conditions plant roots may avoid areas of the soil with high levels of soluble salts. In a greenhouse study, roots are confined to the pots in which they develop and leaching is prevented. This study does indicate that leaching the soil with a volume of water equal to twice the total soil porosity will remove the growth inhibiting effects of kelp applications up to 120 t ha^{-1}. The volume of water used to leach the soils in this investigation was approximately the same amount of rainfall which fell upon the Westham Soil between the 1981 and 1982 field season (Section 3.1). This investigation does support the hypothesis that many of the reported crop growth effects

documented in the field experiment (Section 3.1) were primarily related to increasing soil water-soluble salt with increasing kelp applications.

3.3.5 Conclusions

Kelp, M. integrifolia, application of 120 t ha^{-1} reduced emergence and yields of beans (P. vulgaris) under greenhouse conditions. The reduced emergence and yields that were measured with these large kelp applications appear to be mainly related to salt or Cl toxicity, although an unknown growth inhibitor(s) may also be implicated. Plant growth responses to soil salt stress, such as reduced emergence, stunted growth, increased moisture content and the dark green colour of plant tissue, were observed in this investigation. Leaching the soil to remove the soluble salts reduced or eliminated these plant symptoms.

CHAPTER FOUR

THE KELP, *Macrocystis integrifolia*, AS A CROP FOLIAR SPRAY.

4.1 Effects of Two Kelp (*Macrocystis integrifolia* and *Ecklonia maxima*) Foliar Sprays on Bean Crop Growth and Nutrition.

4.1.1 Introduction

Field studies were designed to investigate the potential use of the kelp, *Macrocystis integrifolia* Bory, processed as a concentrate for use as a kelp foliar spray on bean (*Phaseolus vulgaris* L.) crop productivity. The kelp itself was harvested in the spring, which assured that kelp plants were actively growing, healthy (North and Zimmerman, 1984) and of the same physiological age. Harvesting the kelp, *M. integrifolia*, in the spring also allows for complete kelp stand reestablishment in the fall by subsequent growth after harvest (Coon, 1983). Spring harvest takes advantage of a time in which fish processing plant facilities along the B.C. coast are underutilized, therefore, a potential kelp processing operation within these plants would be complimentary and could enhance their

viability (D. Cruickshank, Seafood Products Company, personal communication).

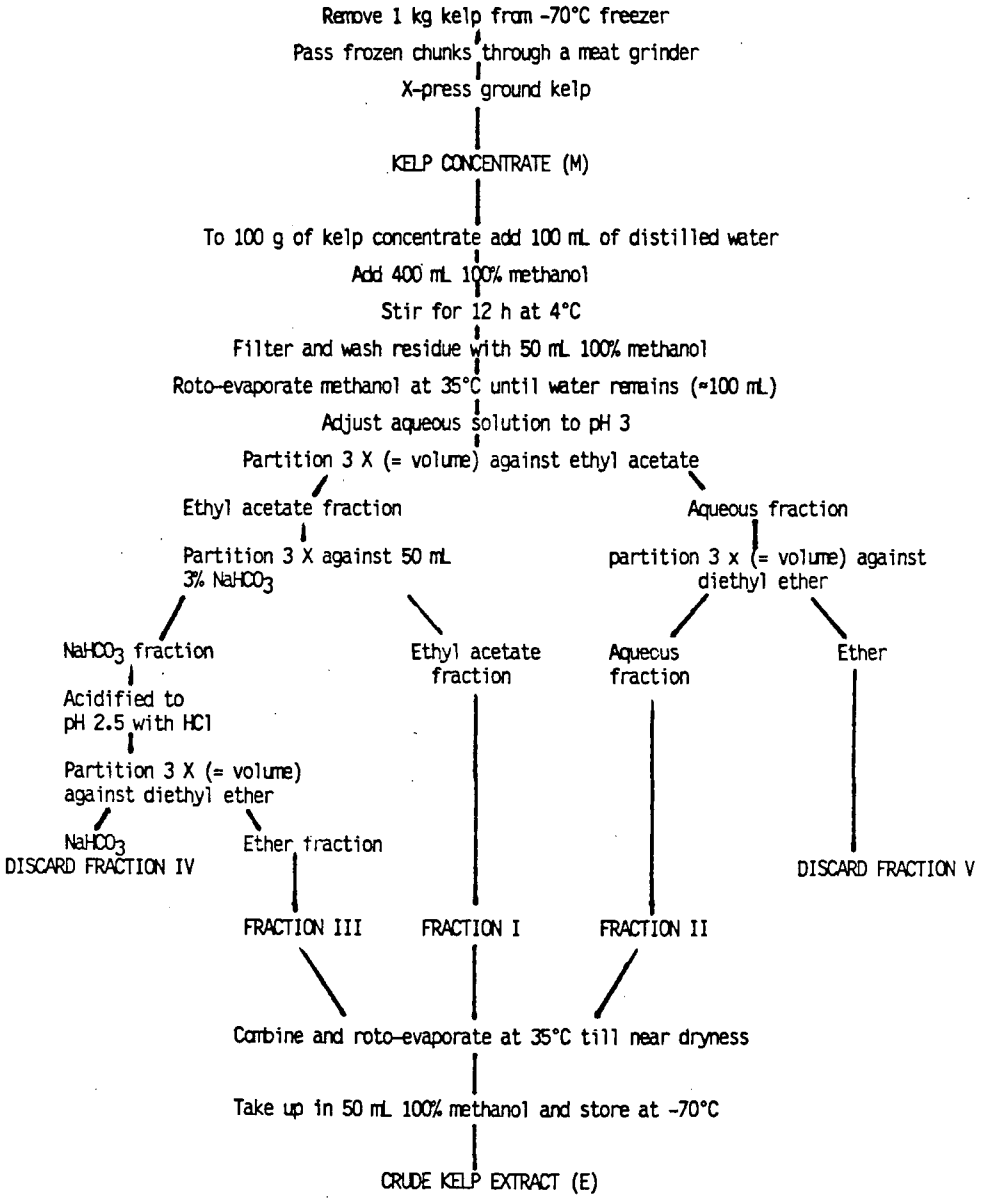
The M. integrifolia kelp concentrate was compared to a crude extract of the concentrate. This was a test of the hypothesis that natural growth promoting phytohormones, such as auxin, gibberellins and cytokinins, may be active constituents. This extract was subsequently bioassayed for the presence of growth-promoting phytohormones cytokinin, auxin and gibberellin-like substances. The commercially available South African kelp (Ecklonia maxima (Osbeck) Papenfuss) concentrate, "Kelpak 66", was applied as an already documented and effective comparison. Crop responses to "Kelpak 66" include increased seed germination and growth and altered plant development and nutrition (Kotze and Joubert, 1980; Donald, 1981; Featonby-Smith and van Staden, 1983a and 1983b; and Nelson and van Staden, 1984a and 1984b). Cytokinin-like substances have also been detected in the kelp concentrate and are suspected to be active constituents (Featonby-Smith and van Staden, 1983b; Finnie and van Staden, 1985).

4.1.2 Material and Methods

Plot experimental design and statistical analysis:
1983 Field Trial: On May 13, 1983 fresh kelp, M. integrifolia, was harvested near Execution Rock, just west of the Bamfield Marine Station, British Columbia (N latitude $48^{o}49'$; W longitude $125^{o}11'$). The rapidly growing apical portion of the plant was harvested, counting twelve laminae back from the scimitar apex (top 1.5 m). Approximately 24 healthy apical portions of the plant were selected from the kelp bed and immediately cut to pieces less than 40 mm in size. The cut kelp was mixed thoroughly and 1 kg portions placed in ziplock plastic bags, air-vented and put on ice in a cooler and transported back to the marine station. The kelp was then immediately frozen ($-15^{o}C$) and transported the next day on ice to the University of British Columbia, where it was transferred to a freezer at $-70^{o}C$.

Table 9 outlines the procedure used for the preparation of the experimental kelp (M. integrifolia) concentrate and its extract. The X-press (AB Biotec) used to process the kelp into a concentrate applies the principle of freeze fracturing ($-25^{o}C$) under high pressure (200,000 to 600,000 kPa) which causes crystallized water to undergo rapid phase

TABLE 9. 1983 FLOW CHART FOR THE PREPARATION OF THE *M. integrifolia* KELP CONCENTRATE (M) AND EXTRACT (E)



changes and forces the kelp through a small orifice (1.0mm). The resulting effect is disintegration of plant cell walls and membranes and reduced particle size.

The resulting concentrate or mash (M) was then subjected to a series of extraction procedures (Table 9) to produce the crude kelp extract (E). This extraction procedure was designed by the author and used methods commonly employed in phytohormonal analysis. It is based upon the recovery coefficients of the various phytohormones for particular solvents at defined pH as described by Murakami, 1970; Mann and Jaworski, 1970; Hemberg, 1974; Atsumi et al., 1976; Ciha et al., 1977; and Walton et al., 1979. In separate extractions the various fractions I, II and III listed in Table 9 were then further purified and/or chromatographed prior to bioassay detection using methods outlined in Table 10. The methods oulined in Table 10 were designed by Radley (UBC Dept. of Plant Sc., personal communication). Fractions IV and V were also tested for bioassay activity. Known natural phytohormones were also chromatographed as outlined in Table 10 for use as reference comparisons to detected activities in the kelp phytohormonal fractions. All standards and references were obtained from

TABLE 10. FRACTIONS I, II AND III PURIFICATION AND/OR CHROMATOGRAPHY STEPS PRIOR TO PHYTOHORMONAL BIOASSAY.

Gibberellin Chromatography Steps

Fraction I

Roto-evaporate at 35°C until near dryness.

↓

Take up in 3 mL volumes (3 x) and apply as a strip with a 1.0 mL syringe to Whatman 3 mm chromatography paper.

↓

Develop in ascending solvent (isopropanol:NH_4OH:water:: 10:1:1) by volume to a height of 10 cm.

↓

Air dry developed chromatography paper in fume hood.

↓

Cut developed paper into 10 equal width strips (0-1.0 R_f) parallel to solvent front.

↓

Plate one end of each strip into 50% acetone and elute the strips as a wick, allowing the solvent to descend, collecting 1.0 mL from other end of each strip.

↓

Known standards in 50% acetone are made at this time.

↓

Proceed with Gibberellin Rice Seedling Sheath Elongation Bioassay described by Murakami, 1970. Each of the R_f samples and standards are applied as a 1.0 µL drop to each of 5 rice seedlings for each of the 3 replicates.

Cytokinin Purification and Chromatography Steps

Fractions I and II combined

Roto-evaporate at 35°C until near dryness.

↓

Take up in 50 mL of 80% ethanol at pH 2.5 and apply to Dowex-50W cation exchange column (bed volume 135 mL) placed in a cold chamber (4°C) using methods described by van Staden, 1976.

↓

Run sample down to top of column at a rate of 10 mL h^{-1}.

↓

Add 350 mL of distilled and degassed water and run down to top of column at a rate of 30 mL h^{-1}.

↓

Add 200 mL of 80% ethanol and run down to top of column at a rate of 20 mL h^{-1}.

↓

Elute sample off exchange column with 1 L of 3N NH_4OH in 50% ethanol.

↓

Roto-evaporate collected sample at 35°C till near dryness.

↓

Apply as a strip with a syringe to a silica gel (Kieselgel 60 F 254; Merck) for thin layer chromatography (TLC) as described by Rademacher and Graebe, 1984.

↓

Develop in ascending solvent (chloroform:methanol 17:3 by volume) to a height of 10 cm.

↓

Air dry developed TLC plate in fume hood.

↓

Cut plate into 10 equal width strips (0-1.0 R_f) parallel to solvent front and scrape gel off each strip into 10 mL test tubes.

↓

Elute each of the stripes with 2 mL of 100% methanol; centrifuge and decant (3 x).

↓

Split each of the 6 mL collected eluate into three 2 mL portions, placing them into 5.5 cm petri dishes which contain two #1 Whatman filter papers. 2 mL portions in triplicate of known standards in 100% methanol are placed in dishes at this step.

↓

Each dish is air dried in a fume hood for 16 h.

↓

Add 2.0 mL of 0.013 M sodium phosphate buffer (pH 6.3) to each dish and proceed with Cytokinin Amaranthus Cotyledon Beta-Cyanin Production Bioassay as described by Biddington and Thomas, 1973. Each of the R_f samples and standards are applied to 10 cotyledons in each dish.

Auxin Chromatography Steps

Fraction III

Roto-evaporate at 35°C until near dryness.

↓

Take up in 3 mL vol. (3 x) and apply as a strip with syringe to a silica gel plate (Kieselgel 60 F 254) for TLC as described by Rademacher and Graebe, 1984.

↓

Develop in ascending solvent (isopropanol:NH_4OH: water 10:1:1 by volume) to a height of 10 cm.

↓

Air dry developed TLC plate in fume hood.

↓

Cut developed plate into 10 equal width strips (0-1.0 R_f) parallel to solvent front and scrape gel off each strip into 10 mL test tubes.

↓

Elute each of the 10 strips with 3 mL of acetone and centrifuge.

↓

Decant off eluate.

Dry down acetone eluate using a stream of N_2 gas.

Wash silica gel residue with 6 mL of 0.01 M KH_2PO_4 buffer (pH 6.4) containing 2% sucrose and centrifuge.

↓

Combine the eluates for each of the 10 samples.

↓

Split each of the 6 mL collected eluate into three 2 mL portions, placing them into 3.5 cm petri dishes. 2 mL portions in triplicate of known standard in buffer/sucrose solution are placed in dishes at this step.

↓

Proceed with Auxin Avena Coleoptile Straight Growth Test Bioassay as described by Nitsch and Nitsch, 1956. Each of the R_f samples are applied to ten 6.0 mm coleoptile segments in each dish.

Sigma Chemical Co., St. Louis, Missouri.

The M. integrifolia kelp concentrate (M) and its extract (E) were stored at -70°C and thawed just prior to being applied to the crop foliage at 2 and 4 L ha^{-1} (kelp concentrate equivalent) diluted with water 1:500 and 1:250 (W/V), respectively. The 4 L ha^{-1} applications for M and E are referred to as M1 and E1 and the 2 L ha^{-1} applications are referred to as M2 and E2, respectively. The South African E. maxima kelp concentrate, "Kelpak 66" (K), (manufactured by Kelp Products Ltd., P.O. Box 465, Cape Town 8000, South Africa), was applied at 4 L ha^{-1}, diluted 1:250 (W/V) with water. The controls (C) were sprayed with an equivalent volume of water. All foliar treatments were applied using a "Solo" backpack sprayer on days 21, 36, 50 and 64 after sowing. Canopy temperatures at the time of spraying were 15°, 22°, 23° and 21°C, respectively.

The plots were located on Reynelda Farms, Westham Island, Ladner, British Columbia. The soil was described in the previous kelp soil amendment field experiments (Section 3.1.2). Each plot measured 2.4 x 4.0 m (spraying area) with four rows of inoculated (Rhizobium leguminosarum biovar phaseoli) bush beans (P. vulgaris cv. Galamor), spaced 0.6 m

apart, planted to a depth of 35 mm on June 15, 1983. The total plot area measured 36.0 x 9.0 m with two rows of plots (12 in each) separated by a 1.0 m walkway. A boundary row of beans separated each of the plot spraying areas. Plots were split into 4 blocks (2 blocks per row of plots) using a randomized complete block design for each of the 6 foliar treatments. At sowing soil pH, %C, %N, available (mg kg^{-1}) P, K, Ca, Mg, Fe, Cu, Mn and Zn were 4.6, 2.7, 0.28, 60, 280, 970, 140, 170, 10, 54 and 5.0 respectively. Methods of soil analysis are described later in the text. Prior to seeding, 200 kg ha^{-1} of 0-0-60 was broadcast and incorporated and during seeding 300 kg ha^{-1} of 11-51-0 was banded 50 mm to the side and below the seed.

At harvest, September 8, 1983 (Day 86), 2.0 m strips were systematically harvested from the middle area of each of the two centre rows of each plot. The harvested plant material (combined leaf and stem and marketable beans) were weighed and randomly sampled for dry weight and elemental analysis using the same methods described in the previous kelp soil amendment investigation (Section 3.1.2). Measured crop growth responses at maturity included fresh and dry weights of shoot, leaf and stem and bean yields, harvest index and fresh/dry weight ratios. Mineral nutritional

responses include the bean and combined leaf and stem elemental concentration and uptake of N, P, K, Ca, Mg, Fe, Cu, Mn and Zn.

Plant growth, development, elemental concentrations and uptake variables of the samples taken at harvest were subjected to analysis of variance with treatment means separated into single degree of freedom comparisons of C vs (M1 + M2 + E1 + E2 + K), K vs (M1 + M2 + E1 + E2), (M1 + M2) vs (E1 + E2), (M1 + E1) vs (M2 + E2) and (M1 + E2) vs (M2 + E1). Significance was at %5 level and coefficients of variation (CV) given.

1984 Field Trial: The 1984 field trial treatments included (a) four of the treatments in the 1983 field trial, which included the control, X-pressed kelp (M. integrifolia) concentrate (applied at 2 and 4 L ha^{-1}) and the commercial kelp concentrate "Kelpak 66" (applied at 4 L ha^{-1}) and (b) a kelp concentrate from M. integrifolia, prepared from an alternative method (applied at 2 and 4 L ha^{-1}) which could be appropriate for commercial manufacture of such a product. The alternative method allowed for the particle size of the kelp concentrate to be carefully controlled by centrifugal dispersion and high pressure homogenization. The dispersion/

homogenization method of producing the kelp concentrate in this investigation was:

1. mincing the kelp with a meat grinder which reduced the kelp to a particle size of approximately 10 mm in diameter;
2. dissolving the preservative (sodium benzoate) and buffer (mono-ammonium phosphate buffer) in water (9 parts kelp slurry to 1 part water containing the preservatives and buffer by volume) and mixing to give a final concentration of 0.1% (w/w) preservative and 0.3% (w/w) buffer;
3. subjecting the kelp slurry containing the buffer and preservatives to high speed centrifugal dispersion (Brinkman Manual) which reduced and further liquified the kelp to particles of less than 1 mm in size;
4. subjecting the liquified kelp to high pressure (25,000 kPa) homogenization using a single stage homogenizer (Gaulin Manual) which reduced the particle size of the kelp to approximately 50 to 100 µm.

This homogenized M. integrifolia kelp or "SeaSpray" (S)

was then bottled and stored at room temperature (20°C) to simulate shelf storage prior to its use in the field investigation. Photographs were taken of the various concentrates using a light microscope with a micrometer inserted for particle size determination.

Kelp (M. integrifolia) was harvested on May 14, 1984 using the same methods and area of kelp harvest described in the 1983 field trial investigation. The X-press method and the storage conditions of the kelp concentrate or mash (M) were described in the 1983 field trial investigation.

Both of the M. integrifolia concentrates (S and M) were applied to the crop at rates of 2 and 4 L ha^{-1} (with S being adjusted to M equivalent because of the additional water in the processing procedure) diluted with water 1:500 and 1:250 (W/V), respectively. The 4 L ha^{-1} application for S and M are referred to as S1 and M1 and the 2 L ha^{-1} applications are referred to as S2 and M2. The South African commercially produced kelp (E. maxima) concentrate, Kelpak 66, was applied at 4 L ha^{-1} (K) diluted 1:250 (W/V) with water. The control (C) was sprayed with an equivalent volume of water. All foliar treatments were applied to plots replicated three times within each of two blocks using

a "Solo" backpack sprayer at mid-afternoon on days 14, 28, 42 and 56 after sowing. Canopy temperatures at the time of spraying were 22^{o}, 20^{o}, 20^{o} and 18^{o}C, respectively. Ambient daily mean temperature and precipitation data were supplied by Environment Canada, Ladner-South Station, located 5 km from the plot site.

The plots were located in a different part of the field from those of the previous 1983 field trial experiment. The type of crop, soil series, methods of seed inoculating and sowing, fertilizer types and applications, were as described in the 1983 field trial. The crop was seeded on July 13, 1984. Each plot measured 4.8 x 6.0 m (spraying area) with 8 rows spaced 0.6 m apart with a boundary row placed between each of the plots. The total plot area was 54.4 x 20.0 m with three rows of plots (12 in each) separated by 1.0 m walkways running between the length of the plots. At sowing, soil pH, %C, %N, available P, K, Ca, Mg, Fe, Cu, Mn and Zn (mg kg^{-1}) were 5.6, 1.9, 0.11, 50, 220, 1500, 260, 160, 9.5, 54 and 5.5, respectively. Methods of soil analysis are discussed later in the text.

On September 29, 1984 (final harvest) 2.0 m strips were systematically harvested from the middle region of each of

the two central rows of each plot, using the same methods described in the 1983 field trial investigation. The harvested plant materials (combined leaf and stem and marketable bean) were weighed and sampled for dry weight determination and elemental concentration analysis using methods described in the previous kelp soil amendment investigation (Section 3.1.2).

On Days 13, 20, 27, 34, 41, 48, 55, 62, 69, and 76 after sowing, twelve soil core samples (0-0.20 m) were taken from within the immediate plot area and placed in soil moisture cans. The soils were dried at 105^{o}C for 24 hours for soil moisture determination. A soil moisture retention curve was constructed for the soil using the porous plate extraction method as described by Richards (1965). Measured soil moisture contents were transformed into soil tension units (kPa) by use of the constructed soil moisture retention curve.

Plant growth, developmental, elemental concentration and uptake variables were subjected to analysis of variance with treatment means separated into single degree of freedom comparisons of C vs (M1 + M2 + S1 + S2 + K), K vs (M1 + M2 + S1 + S2), (M1 + M2) vs (S1 + S2), (M1 + S1) vs (M2 + S2),

and (M1 + S2) vs (M2 + S1). Significance was at the 5% level and coefficients of variation (CV) given.

Soil pH, %N, %C and available P, K, Ca, Mg, Fe, Cu, Mn and Zn were used as soil covariates for both 1983 and 1984 crop dry yield variables. The covariates used for each elemental uptake and concentration for both the combined leaf and stem and bean pod plant tissue were soil pH, %C and the measured soil covariate for the particular foliar nutrient in question. Analyses of covariance were interpreted according to Little and Hills (1978).

Leaf and Soil Analyses: Combined leaf and stem samples were analyzed for total N, P, K, Ca, Mg, Fe, Cu, Mn and Zn concentrations and subsequently used for calculating the elemental uptakes using methods described in Section 3.1.2. The M. integrifolia and E. maxima kelp concentrates were dried at 70^{o}C for dry weight determination and ground using a mortar and pestle. One gram (1.000 g) of kelp was then analyzed for elemental concentration using the same methods as above for the bean samples. The M. integrifolia phytohormonal extract (E) was also analyzed for the above elements by placing 5.00 mL (the equivalence of 10 g dry of kelp) in a digestion tube, drying off the methanol with a

stream of air and then proceeding with the digestion. All plant elemental concentrations were expressed on a dry weight basis.

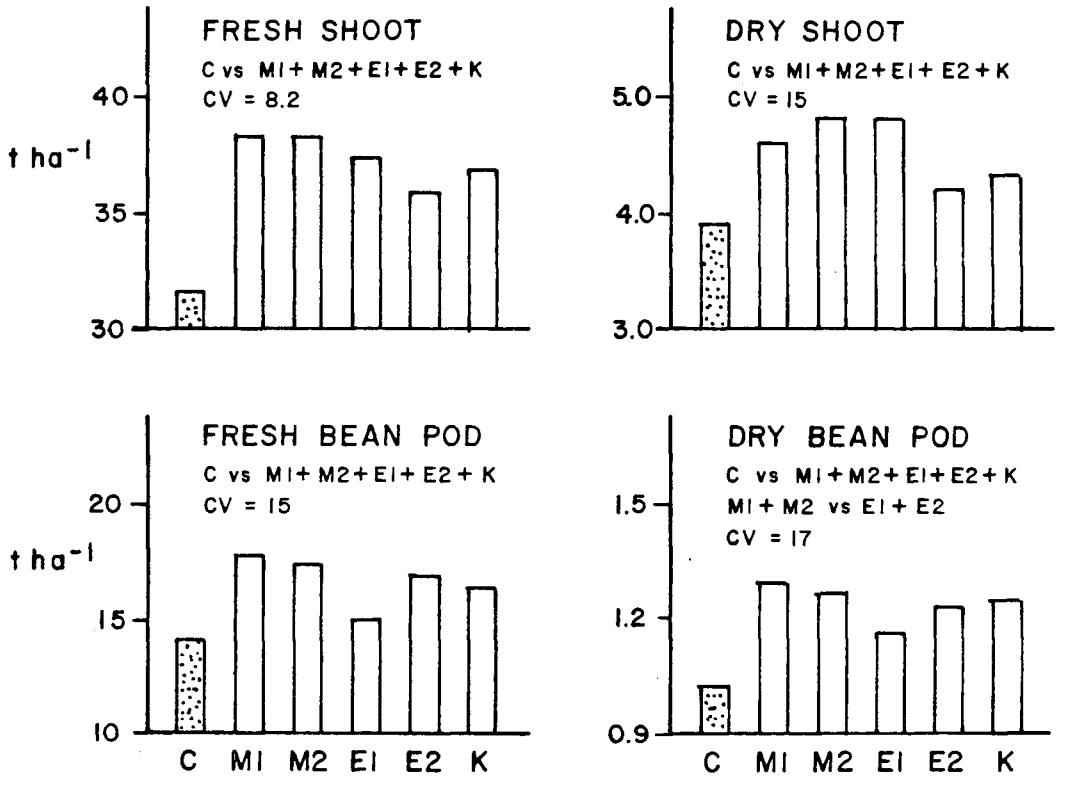
One day prior to the first foliar spraying four soil core samples (0-0.20 m) were taken systematically from between the rows of each plot and composites made for each of the blocks. On the harvest date, 12 soil samples (0-0.20 m) were systematically taken from each plot and composited. Each of the air dried soil samples was analyzed for pH, %C, total %N and available P, K, Ca, Mg, Fe, Cu, Mn and Zn (mg kg^{-1}). The methods of analysis for soil pH, %C, available P and %N were described in the previous kelp soil amendment field investigation (Section 3.2.1). Available soil K, Ca and Mg were determined by extracting 5.000 g of soil with 50.0 mL of Morgan's Extraction Solution using methods described by Greweling and Peech (1965). Available Fe, Cu, Mn and Zn were determined by extracting 10.000 g of soil with 50.0 mL of 0.1M HCl using methods described by Fiskell (1965). Soil extract concentrations of K, Ca, Mg, Fe, Cu, Mn and Zn were determined using a Perkin and Elmer 330 atomic absorption spectrophotometer.

4.1.3. Results and Discussion

1983 and 1984 analysis of variance and covariance F-values, mean square error and treatment means and adjusted means for plant yields, elemental concentration and uptake variables are presented in Appendices 14 through 19.

Under 1983 and 1984 field conditions both the M. integrifolia and E. maxima kelp concentrates (S, M and K) or the phytohormonal extract (E), applied at either 2 or 4 L ha^{-1}, as a foliar spray, were effective in increasing fresh and dry marketable bean pod yields (Figures 12 and 13). Shoot yield increases were related to increased bean pod yield as combined leaf and stem yields were not affected. In 1983 the M. integrifolia kelp concentrate (M) was more effective in increasing dry bean pod yields than its phytohormonal extract (E).

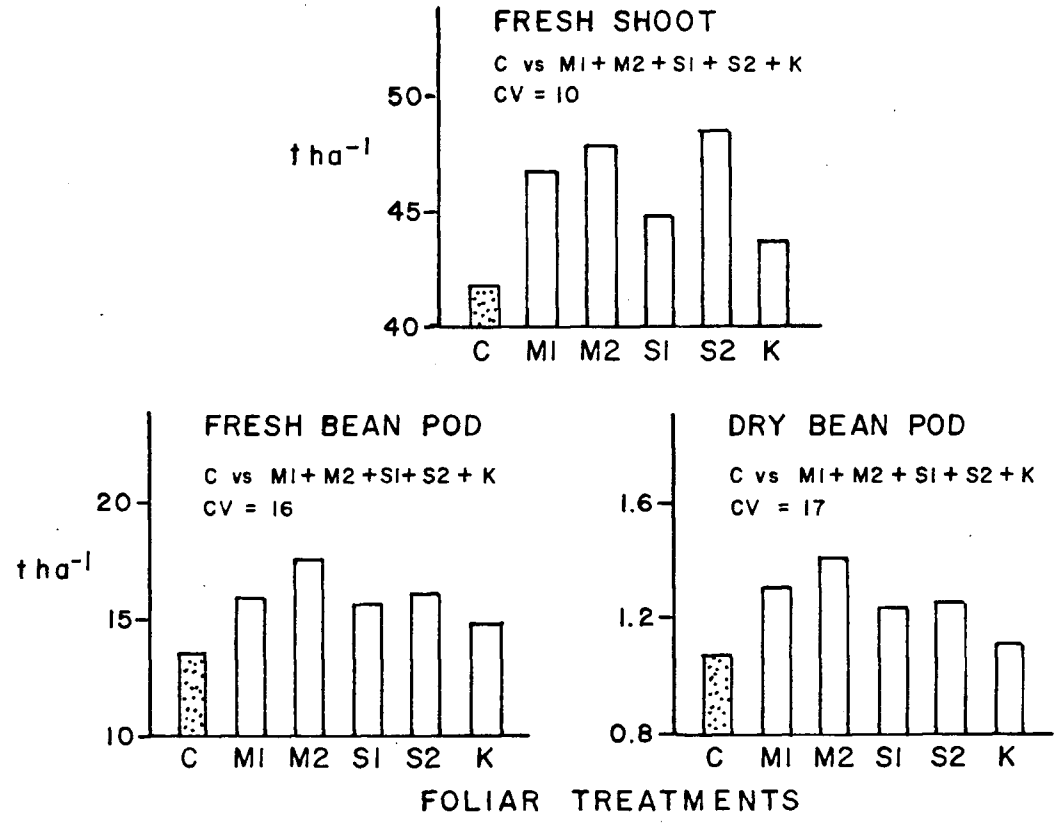
Cytokinin, gibberellin and auxin-like substances were detected in the chromatographic fractions of the M. integrifolia phytohormonal extract, which consisted of fractions I, II and III subsequently combined (Figure 14). Active Rf values for cytokinin matched closely those of zeatin (Z) and its riboside (ZR) and isopentenyl adenine (IPA) and its riboside (IPAR). Active Rf values for gibberellin were detected in the broad central region of the



FOLIAR TREATMENT LEGEND: Control (C); M. integrifolia kelp concentrate produced with an X-Press and applied at 4 L ha^{-1} (M1) and 2 L ha^{-1} (M2); M. integrifolia phytohormonal extract applied at a kelp concentrate weight equivalence of 4 L ha^{-1} (E1) and 2 L ha^{-1} (E2) and E. maxima kelp concentrate applied at 2 L ha^{-1} (K).

FIGURE 12.

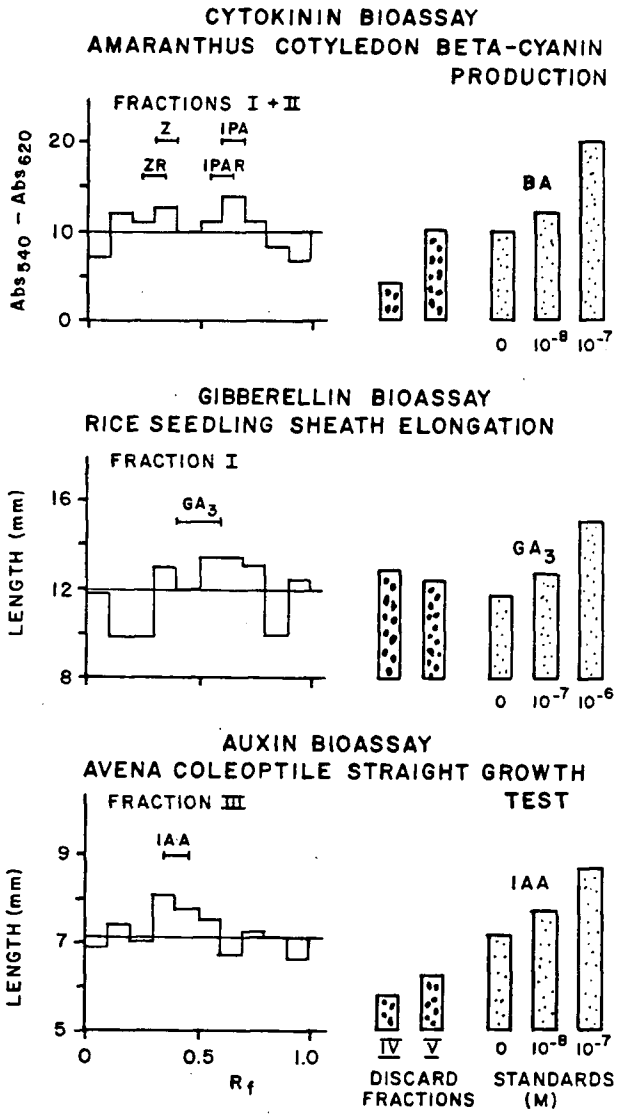
1984 BEAN PLANT GROWTH



FOLIAR TREATMENT LEGEND: Control (C); M. integrifolia kelp concentrate produced with an X-Press and applied at 4 L ha^{-1} (M1) and 2 L ha^{-1} (M2); M. integrifolia kelp concentrate produced by dispersion/homogenization method and applied at 4 L ha^{-1} (S1) and 2 L ha^{-1} (S2) and E. maxima kelp concentrate applied at 2 L ha^{-1} (K).

FIGURE 13.

PHYTOHORMONAL BIOASSAY ACTIVITIES



PHYTOHORMONAL BIOASSAY LEGEND: Histograms are phytohormone-like activities of the M. integrifolia extract (E) for each of 10 eluted chromatograph sections (Rf) of FRACTIONS I, II and/or III, described in Table 9. Shaded bars are activity levels for discard fractions (IV and V) and standards (M) used (BA, benzyladenine; GA3, gibberellic acid 3 and IAA, indoleacetic acid). Horizontal bars above each of the histograms are the Rf regions for the chromatographed standards (Z, zeatin; ZR, zeatin riboside; IPA, isopentenyl adenine; IPAR isopentenyl adenine riboside; GA3, gibberellic acid 3 and IAA, indoleacetic acid).

FIGURE 14.

chromatograph (Rf 0.4 to 0.8) with the known gibberellin GA_3 chromatographing from Rf 0.5 to 0.7 of this region. Active Rf values for auxin match closely that of indoleacetic acid (IAA). No cytokinin and auxin-like bioassay activities were detected in the discard fractions IV and V, which were excluded form the phytohormonal extract, although some gibberellic-like activity was detected.

According to Finnie and van Staden (1985) the concentration of the E. maxima concentrate in solution is an important factor controlling the growth regulating efficacy. A 1:100 (v/v) dilution (kelp concentrate:water) was inhibitory, while higher dilutions (1:400 to 1:600) were growth promoting. Upon chromatographing the E. maxima kelp concentrate they also demonstrated that several growth regulating substances were present, each of which elicited different plant growth and developmental responses. Similarly, Featonby-Smith and van Staden (1987) also demonstrated differences in barley grain yield components (number of ears and number of grains ear^{-1}) with varying dilutions of the E. maxima concentrate (1:250 and 1:500 dilutions). In this investigation the differences in marketable dry bean yields between the M. integrifolia kelp concentrate (M) and its phytohormonal extract (E) may be

related to altered concentrations of one or more active growth regulating substances. Such effects could have been caused by (a) low or varying extraction efficiency for particular growth regulating substances from the concentrate, (b) omission of growth regulating substances from the extract, (c) presence of inhibitory substances and/or (d) deactivation of growth regulating substances during the extraction procedure.

As was discussed earlier in the introduction (Section 4.1.1) the cytokinin phytohormones have been suspected to be active constituents of kelp foliar treatments. However, it has not been demonstrated that cytokinin-like substances detected in these concentrates or extracts are indeed physiologically active under field or greenhouse conditions. Table 11 summarizes cytokinin and cytokinin-like concentrations recorded for various kelp extracts and concentrates used as foliar sprays, including the M. integrifolia concentrate. The range of the cytokinin-like equivalent concentrations given for the M. integrifolia concentrate is related to the fresh weight of kelp concentrate which was extracted and chromatographed prior to the callus bioassay. The lower the weight of the kelp in the extract to be chromatographed the higher the cytokinin-

TABLE 11. SUMMARY OF CYTOKININ OR CYTOKININ-LIKE CONCENTRATIONS OF VARIOUS KELP EXTRACTS AND CONCENTRATES

TRADE NAME	TYPE OF KELP	CYTOKININ/ CYTOKININ-LIKE CONCENTRATION	METHOD OF ANALYSIS	REFERENCE
Seasol or Agrikelp	*Durvillea potatorum*	63 µg L^{-1} *(10^{-7} M)	GC/MS	Tay *et al.*, 1985
Maxicrop	*Ascophyllum nodosum*	1300 µg L^{-1} (10^{-6} M)	Tobacco callus bioassay	Sanderson and Jameson, 1986
Kelpak 66	*Ecklonia maxima*	**26 µg L^{-1} (10^{-7} M)	Soybean callus bioassay	Featonby-Smith and van Staden, 1983
SeaSpray	*Macrocystis integrifolia*	84-1680 µg L^{-1} (10^{-7} to 10^{-6} M)	Soybean callus bioassay	Radley (personal comm.)

*Approximate molar concentrations in brackets (219 g $mole^{-1}$).

**Calculations based on 1000 g of kelp concentrate $litre^{-1}$.

like activity calculated, with the lower activity value being related to higher kelp equivalent weights in the extract (R. Radley, 1987, UBC Dept. of Plant Sc., personal communication). These results demonstrate that the methods chosen can greatly influence the calculated bioassay activities and misleading results which can be obtained when bioassays are used in quantifying activity levels. For these reasons the concentrations of the various phytohormone-like substances which were detected in the phytohormonal extract (E) of this investigation are not presented. The effectiveness of this phytohormonal extract in promoting the bean yields supports, in part, the thesis that phytohormones or organic compounds may be active constituents of the M. integrifolia kelp concentrate. Research efforts directed at further purification and fractionation of the various phytohormones, in particular cytokinins, using physiochemical methods of analysis with known extraction efficiencies prior to foliar application are warranted.

Nutrient levels in the phytohormonal extract were below the limits of detection, and it is doubtful that the small quantities of nutrient elements applied to the foliage via the pure kelp concentrates (Table 12) would significantly

TABLE 12. ELEMENTAL COMPOSITION OF DRY KELP CONCENTRATES AND FOLIAR ELEMENTAL APPLICATION TO CROP AREA

	ELEMENTAL CONCENTRATIONS OF CONCENTRATES			ELEMENTAL APPLICATIONS		
ELEMENT	UNIT	*M. integrifolia*	*E. maxima*	UNIT	*M. integrifolia*	*E. maxima*
N	%	1.00	32.6	kg ha^{-1}	0.0081	1.14
P	%	0.23	4.3	kg ha^{-1}	0.0019	0.15
K	%	8.5	3.3	kg ha^{-1}	0.070	0.080
Ca	%	1.2	0.21	kg ha^{-1}	0.0010	0.004
Mg	%	0.82	0.10	kg ha^{-1}	0.006	0.002
Fe	mg kg^{-1}	560	5	g ha^{-1}	0.460	0.009
Cu	mg kg^{-1}	4	4	g ha^{-1}	0.003	0.007
Mn	mg kg^{-1}	10	3	g ha^{-1}	0.008	0.005
Zn	mg kg^{-1}	21	10	g ha^{-1}	0.017	0.017
Dry matter	%	10.2	22.0	Kg ha^{-1}	0..81	1.76

contribute to the total shoot mineral nutrient requirement. The E. maxima concentrate was found to have relatively high dry weight N and P concentrations. These high levels are related to the addition of mono-ammonium phosphate and a nitrogen fertilizer during its manufacture.

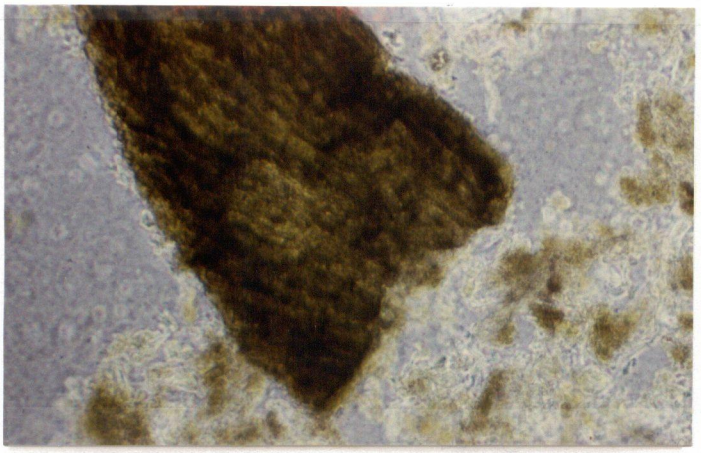
Blunden (1977) examined the elemental composition of various kelp extracts and concluded that the quantities of kelp foliar spray applied could not supply a significant portion of the annual requirements of macronutrients to a crop, but could perhaps supply an amount of limiting nutrient to correct a marginal deficiency only. Kotze and Joubert (1980) in their investigation of rye and cabbage concluded that because kelp foliar sprays were found to be effective only on soils which were fertilized, the response could not be attributed to the mineral nutrition of the kelp. Finnie and van Staden (1985) have also demonstrated that the effectiveness of a kelp foliar spray to promote growth is lost subsequent to the ashing of the kelp concentrate. Although it is doubtful that the heightened responses obtained from the use of kelp foliar sprays could be attributed to the mineral constituents of the kelp, it has not yet been demonstrated that synergistic effects between its mineral nutrient elements and growth regulating

substances do not exist. Recent investigations have documented synergistic effects on plant growth to foliar applications of various elements with phytohormones (Marschner, 1982; Mengel and Kirkby, 1982; Neuman and Nooden, 1983).

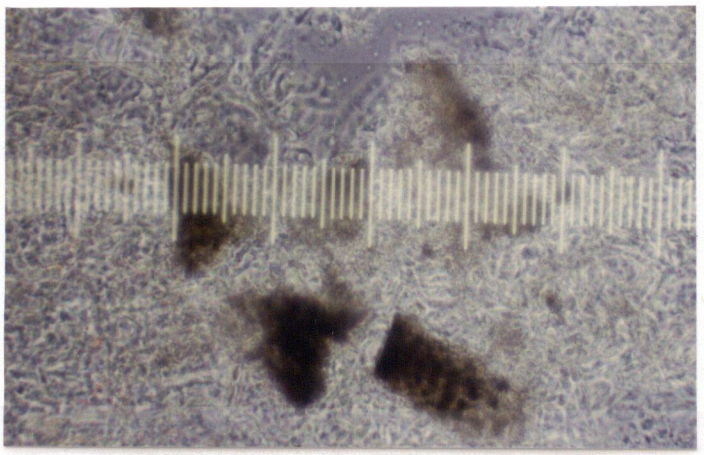
The commercially produced E. maxima kelp concentrate (K) and the experimental M. integrifolia kelp concentrate (S) produced by the dispersion/homogenization method had a similar physical appearance and relatively uniform particle size (50 to 100 µm; Figure 15). The "X-pressed" M. integrifolia concentrate was effective in disintegrating or disrupting plant cell wall material, but particle sizes were non-uniform and many were large enough to plug foliar applicator nozzles. The smallest most commonly used farm foliar applicator nozzles have 50 mesh size (298 µm) filters (Brandt Industries Ltd.) Since the M. integrifolia concentrate produced by the dispersion/ homogenization method was effective in increasing marketable bean yields, it could be a practical manufacturing technique.

Relative to the untreated control, kelp foliar treated plants had similar nutritional responses (Figure 16 and 17). Nutritional responses to kelp foliar treatment, relative to

PHOTOGRAPHS OF KELP CONCENTRATES
(all photographs at same magnification)

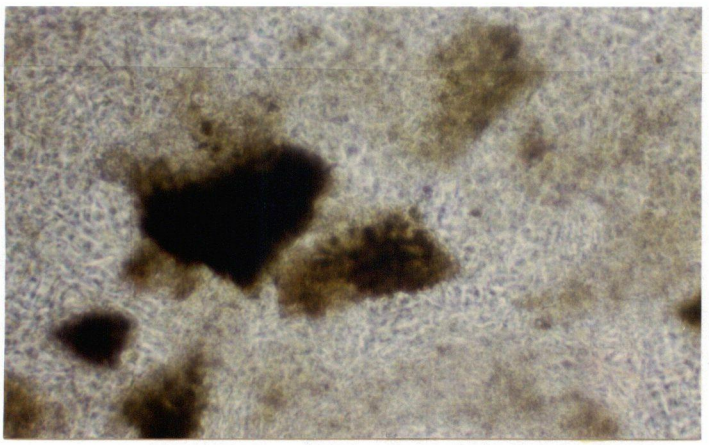


X-PRESSED
M. integrifolia



HOMOGENIZED
E. maxima

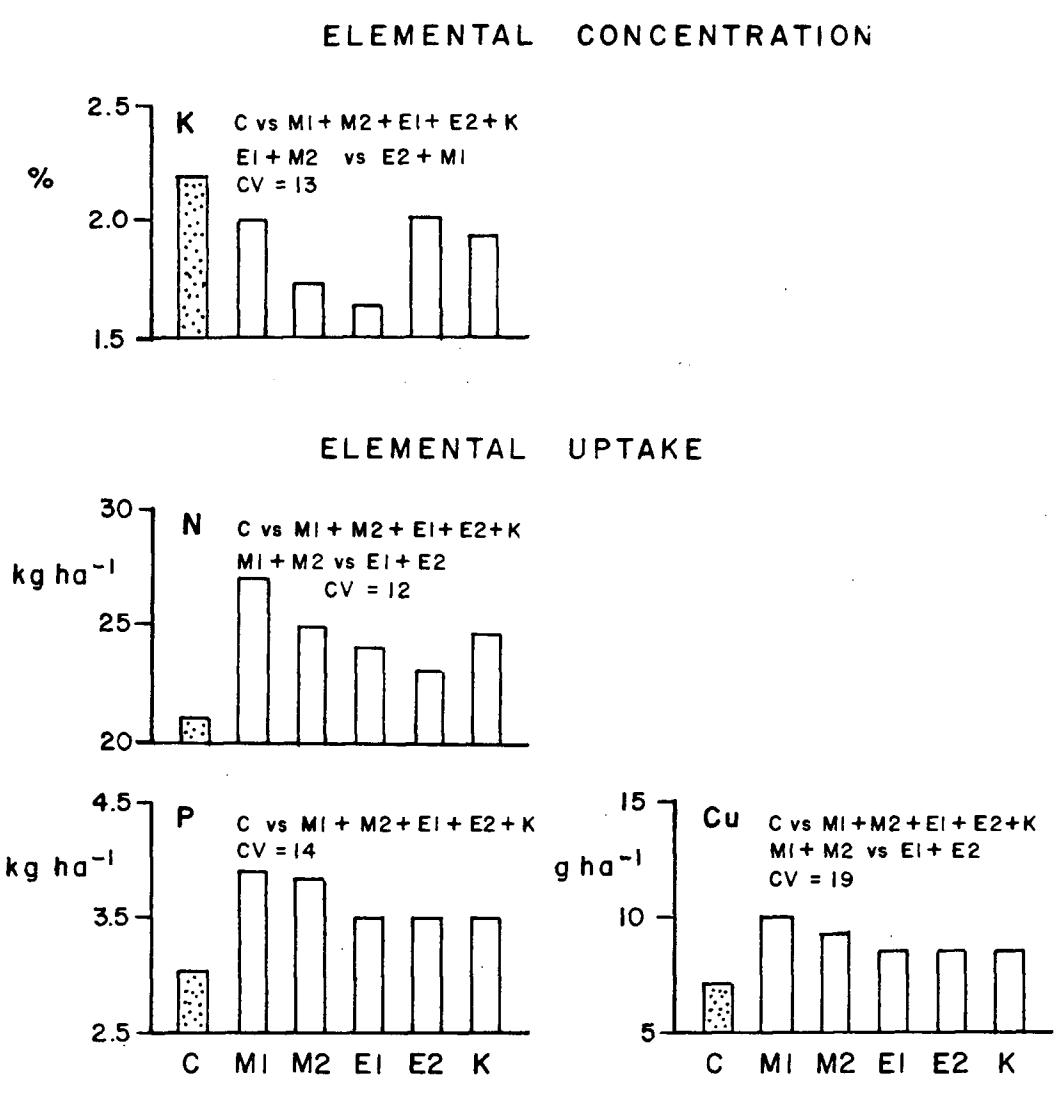
each notch = 10^{-5} m



HOMOGENIZED
M. integrifolia

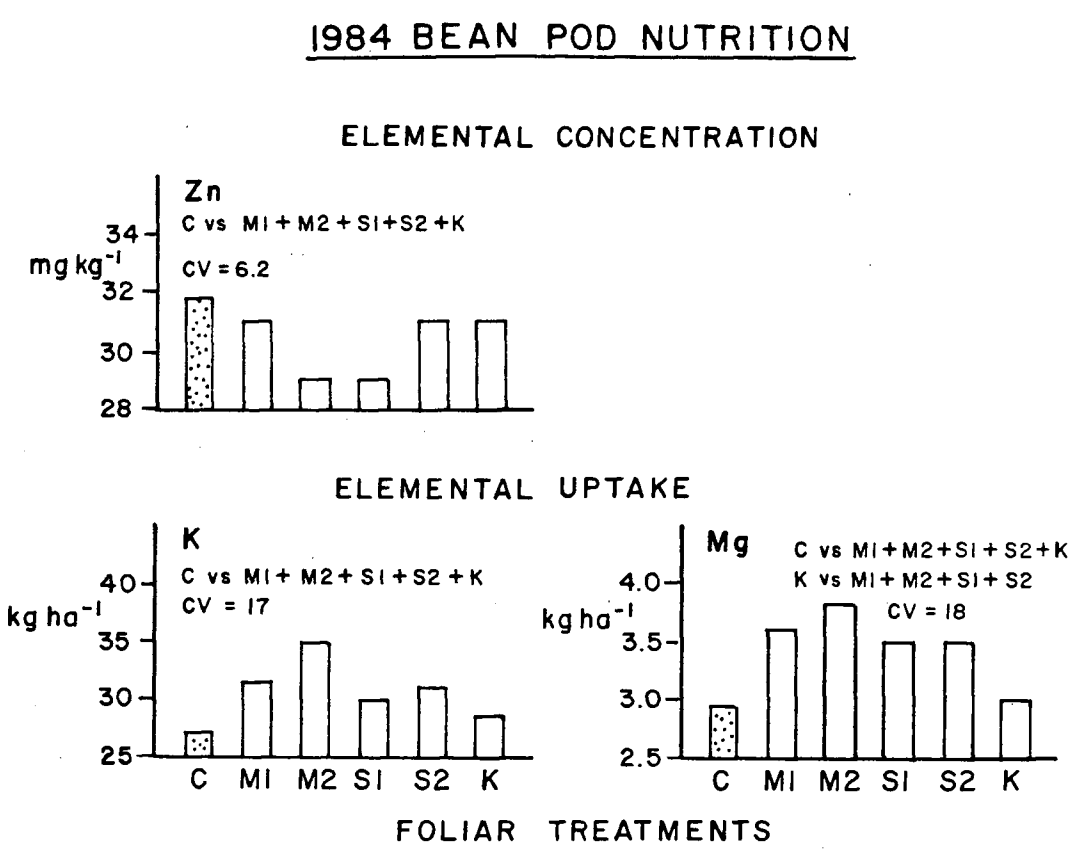
FIGURE 15

1983 BEAN POD NUTRITION



FOLIAR TREATMENT LEGEND: Control (C); M. integrifolia kelp concentrate produced by an X-Press and applied at 4 L ha^{-1} (M1) and 2 L ha^{-1} (M2); M. integrifolia kelp concentrate produced by dispersion/homogenization method and applied at 4 L ha^{-1} (S1) and 2 L ha^{-1} (S2) and E. maxima kelp concentrate applied at 2 L ha^{-1} (K).

FIGURE 16.



FOLIAR TREATMENT LEGEND: Control (C); M. integrifolia kelp concentrate produced by an X-Press and applied at 4 L ha^{-1} (M1) and 2 L ha^{-1} (M2); M. integrifolia kelp concentrate produced by dispersion/homogenization method and applied at 4 L ha^{-1} (S1) and 2 L ha^{-1} (S2) and E. maxima kelp concentrate applied at 2 L ha^{-1} (K).

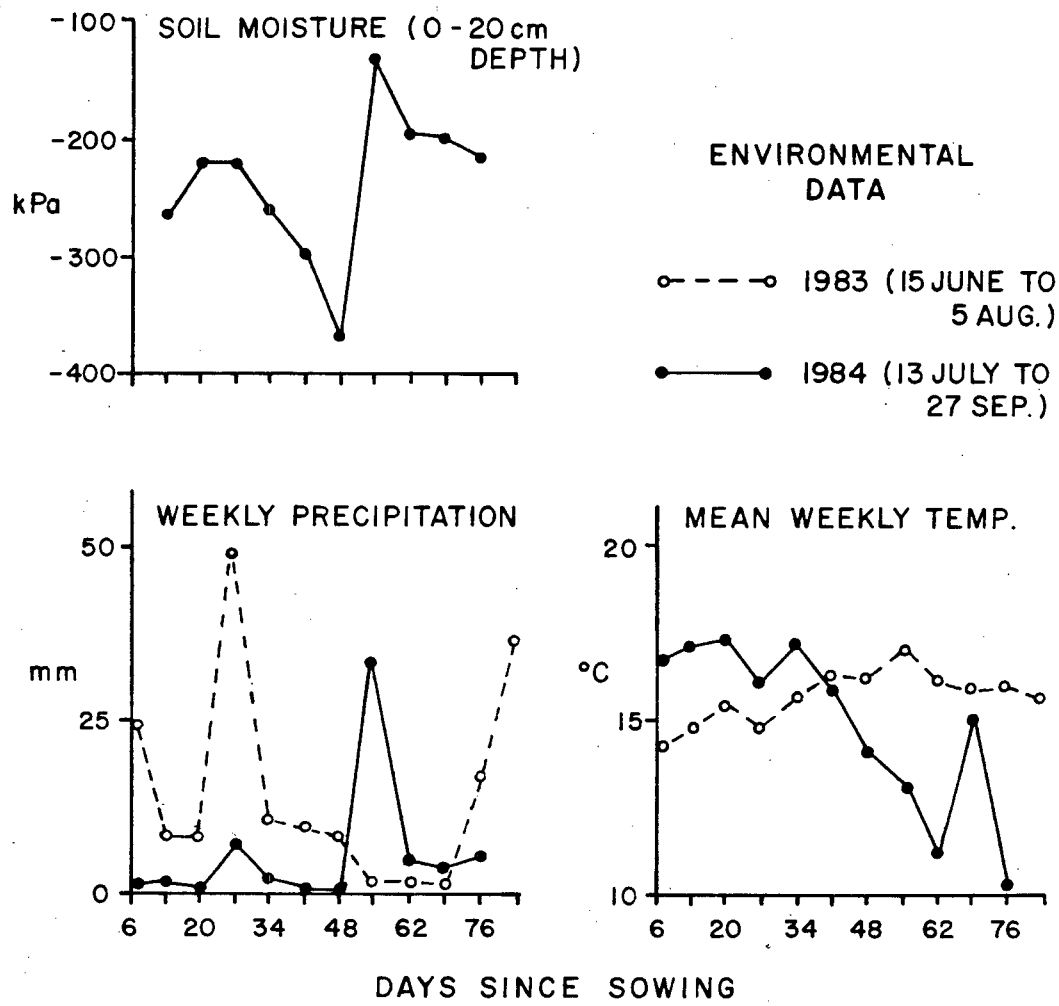
FIGURE 17.

the untreated plants, included reduced bean pod K concentrations and enhanced uptake of N, P and Cu in 1983, whereas, in 1984 bean pod Zn concentrations were reduced as K and Mg uptake was increased. Such kelp foliar spray effects upon elemental concentrations may be related to greater dry matter accumulation per unit element or "dilution effects" as described by Jarrell and Beverly (1981). It has been demonstrated that elemental concentration can increase and uptake decrease as plant dry matter yields decline in response to any factor that limits growth, be it light, biota, moisture, temperature or a nutrient (Martin and Matocha, 1973; Gerakis et al., 1975). Therefore, relative to kelp treated plants, the control plants may have experienced greater strain or more limited growth.

Although the nutritional effects were similar between the 1983 and 1984 field trial the particular mineral nutrient effected was different. Such qualitative dissimilarities may be related to differences in the plant growth environment between seasons. According to Martin and Matocha (1973) the chemical composition of any plant is a result of the interaction of nutrient supply and plant growth. The soil chemical analysis of the plot area

indicates that the 1984 plot site, compared to the 1983 plot site, had higher soil pH (5.6 vs 4.6) and available Ca (1500 mg kg^{-1} vs 970 mg kg^{-1}) and lower %C (1.9% vs 2.7%) and total %N (0.11% vs 0.28%).

The weather conditions in the two years were also different (Figure 18). The 1983 field season started off with an initial short dry period during emergence followed by a long wet, cool and overcast growth environment. The 1984 field season started off with a prolonged dry period followed by a short cool and wet growth period during seed set. Many environmental factors such as soil moisture, light, ambient temperatures, biota and humidity can have a significant effect upon subsequent growth, development and/or mineral nutrition (Woodward and Begg, 1976; Tinker 1980; Jarrell and Beverly, 1981). Therefore, under field conditions weather may be an important factor controlling kelp foliar spray treatment effects upon growth, development or mineral nutritional responses. Abetz (1980) stated that growth responses to various kelp extracts were greatest when crops encounter an environmental stress such as drought. Gupta and MacLeod (1982) indicated that in their field trial the lack of any wheat growth response to kelp foliar treatment may have been related to the favourable



LEGEND: Field enviromental conditions during the growth periods of 1983 and 1984.

FIGURE 18.

environmental growth conditions for that particular growing season. Controlled environment investigations documenting the interactive effects or efficiency of kelp foliar spray treatments with the physical environment are warranted.

In 1983 there were no mineral nutritional differences between the E. maxima and M. integrifolia kelp foliar treatments. In 1984 the E. maxima, relative to the M. integrifolia, kelp concentrate foliar treatments had lower bean pod Mg uptake (Figure 17). Such a response may have been related to lower yields with the E. maxima foliar treatment. Such dissimiliarities between field seasons may also imply that under differing environmental conditions the E. maxima and M. integrifolia kelp foliar treatment effects upon growth, development and mineral nutrition may diverge.

In 1983, plants which were treated with the M. integrifolia kelp concentrate, relative to its phytohormonal extract, had greater dry bean pod yields and N and Cu uptakes, probably as a result of increased bean pod yields (Figure 16).

4.1.4 Conclusions

Under 1983 and 1984 field conditions both the M.

integrifolia and E. maxima kelp concentrate, applied at either 2 or 4 L ha^{-1} as a foliar spray, increased the yields of marketable beans. A crude phytohormonal extract of the M. integrifolia was also effective in increasing marketable bean yields, although less effective than its pure kelp concentrate. Cytokinin, auxin and gibberellin-like substances were detected in the chromatographic fractions of the M. integrifolia phytohormonal extract.

In each field season the qualitative mineral nutritional responses to kelp foliar treatment, relative to the controls, included reduced bean pod elemental concentrations and greater mineral uptakes as dry matter yields increased. Qualitative differences between the two field seasons varied with respect to the particular mineral elements affected. The nutritional responses to kelp foliar treatment, relative to the untreated plants, included reduced bean pod K concentrations as the uptake of N, P, and Cu were enhanced in 1983, whereas, in 1984 bean pod Zn concentrations were reduced as K and Mg uptake was increased. Bean plant mineral nutritional responses to the E. maxima foliar treatment did not differ from those of the M. integrifolia foliar treatment in the 1983 field trial, but differences were experienced in the 1984 field trial.

4.2 Effects of Two Kelp (Macrocystis integrifolia and Ecklonia maxima) Foliar Sprays on Bean Crop Growth and Nutrition Under Varying Soil Moisture Regimes

4.2.1 Introduction

Recent field plot trials have demonstrated that the South African kelp (E. maxima) concentrate "Kelpak 66" and the British Columbia kelp (M. integrifolia) concentrate, when diluted with water prior to foliar application, were effective in increasing bean (P. vulgaris) yields. According to Abetz (1980) and Gupta and MacLeod (1982) kelp foliar sprays may be effective in increasing marketable yields of various crops under environmental stress conditions. To the author's knowledge, there has been no documented research which supports the claim that kelp foliar sprays are most effective under water stress conditions.

Environmental factors, such as drought and waterlogging decrease yields, increase plant elemental concentrations but reduce total uptake (Mengel and Von Braunshweig, 1972; Mattison, 1973; Gerakis et al., 1975; Marais and Wiersma, 1975; Nambiar, 1976; Datta, 1985). In 1983 and 1984 field

trials (see Section 4.1) such nutritional effects were recorded with control plants relative to kelp treated plants, which could suggest that kelp treated plants experienced less strain or exhibited greater tolerance toward their growth environment. Reduced elemental concentrations and increased uptake by kelp treated plants, relative to the untreated plants, could indicate so-called "dilution effects" or greater dry matter accumulation per unit element as described by Jarrell and Beverly (1981).

The mineral nutritional responses were not consistent between the 1983 and 1984 field trials and may have been related to differences in plant growth and developmental response to particular growth environments. Interactive effects between the environment and plant may be important factors which determine the efficacy of kelp foliar sprays and the types of plant growth and nutritional responses recorded with their use.

The objective of this greenhouse investigation was to determine the effect of the kelps M. integrifolia and E. maxima prepared as foliar sprays on bean (P. vulgaris) growth, development and mineral nutrition under varying soil moisture conditions.

4.2.2 Materials and Methods

Bush beans (P. vulgaris cv. Galamor) were grown in the greenhouse for 62 days between May 30 and July 31, 1984. Treatments consisted of three foliar sprays and three soil moisture regimes in a 3 x 3 factorial experiment. There were two blocks with three replicates within each of the blocks. Each of the 108 pots in the experiment was initially planted with five seeds and then selectively thinned to two plants per pot on Day 12. Prior to planting, all the seeds were placed on a sieve, wetted thoroughly and inoculated with Rhizobium leguminosarum biovar phaseoli.

To each of the sterilized 0.15 m high, 2300 mm^3 pots, 1.95 kg of dry sandy loam soil was packed to a bulk density of 850 kg m^{-3} with a total porosity of 0.68 m^3 m^{-3}. A soil water retention curve was constructed for this soil using the porous plate extraction method (Richards, 1965). The soils were analysed for total nitrogen (%N), total carbon (%C), pH and available P, K, Ca, Mg, Fe, Cu, Mn and Zn using the methods described in the 1983 field crop trial (Section 4.1.2). The soil had a pH of 6.6 and total %N and %C concentrations of 0.41 and 6.6, respectively. Available P (Bray 1) was 200mg kg^{-1}, and the available Ca, K and Mg

concentrations (Morgans Extraction Solution) were 3600, 525 and 550 mg kg^{-1}, respectively. The 0.1M HCl extractable Fe, Cu, Mn and Zn concentrations were 55, 5, 130, 40 mg kg^{-1}, respectively. To each pot of soil 145 mg of 0-0-60 (150 kg ha^{-1} equivalent) and 290 mg of 11-55-0 (300 kg ha^{-1} equivalent) fertilizer was added and mixed thoroughly prior to planting.

The soil moisture regimes used in the experiment were field capacity (FC; -30 to -50 kPa), dry (D; -120 to -150 kPa) and wet (W; 0 to -10 kPa). For the field capacity and dry soils, the soil moisture retention curve was used to calculate the weight of soil equivalent to their respective soil water potentials, and pots were weighed each day and twice on sunny days to maintain the soils at the upper end of the desired water potential range. The lower water potential for the range of values given for the field capacity and dry soil treatments relate to the average loss of soil water due to evapotranspiration. The wet soil water treatment was maintained by keeping the pots in a 0.06 m high dish filled with water. The wet soil water potential range represents the soil moisture content from the top of soil (-10 kPa) to the water table (0 kPA).

All pots were maintained at field capacity from seeding until Day 17. On Day 17, dry and wet soil moisture treatments were initiated. Wet soils had their pans filled with water and dry soils were allowed to lose water to their defined water potentials, while field capacity soils were maintained at their water potential during the entire experiment. The plants (Day 17) had fully developed primary leaves, and the first trifoliates were beginning to expand.

At the onset of flowering (Day 37) the dry and wet soil moisture period was ended and half of the pots were harvested. The remaining pots were re-randomized with the dry and wet soils returned to field capacity. The wet soils did not have their pans refilled and were not watered until their soil water potential had fallen below field capacity. All remaining pots were maintained at field capacity until harvest (Day 62).

The foliar sprays consisted of the control (C) sprayed with water, the commercial South African kelp (E. maxima) concentrate "Kelpak 66" (K), and the M. integrifolia experimental kelp concentrate (S) both diluted 1:250 with distilled water. The M. integrifolia experimental concentrate (S) was produced using the dispersion/

homogenization method described in the 1984 field trial experiment (Section 4.1.2). All sprays were applied with a hand held atomizer until the foliage dripped. Spraying occurred on Days 13, 21, 39 and 49.

Plants were harvested on Days 37 (onset of flowering) and 62 (maturity). On each of the respective harvest dates the plant height, number of nodes, leaf area and shoot fresh weight were recorded. The roots were excavated the next day from each pot by careful washing of the roots. Prior to drying the roots, nodulation was rated on a scale of 1 to 3 by five independent observers (1 = light, 2 = medium and 3 = heavy). The plant leaves, stems, beans (greater than 60 mm in length, final harvest only) and roots were oven dried at $70^{o}C$. On the final harvest (Day 62) the number of marketable beans for each pot was recorded. Calculations for each pot included fresh/dry weight ratios of the shoot, dry shoot/root ratios, specific leaf area (SLA-leaf area divided by dry leaf weight) and leaf area ratio (LAR-leaf area divided by the dry plant weight).

Dry samples of leaf plus stem and beans were ground through a stainless steel Wiley mill, (1 mm screen) with a 1.000 g sample used for elemental analysis. The methods of

digestion and determination of N, P, K, Ca, Mg, Fe, Cu, Mn and Zn concentrations were described in the kelp soil amendment field trial experiment (Section 3.1.2).

Plant growth parameters, elemental concentrations and uptake variables were subjected to analysis of variance for each of the two harvests. Foliar treatment means were separated using single degree of freedom contrasts into C vs (K + S) and K vs S, and soil moisture treatments separated into FC vs (D + W) and D vs W. The interactions were separated into C vs (K + S) * FC vs (D + W), C vs (K + S) * D vs W, K vs S * FC vs (D + W) and K vs S * D vs W. Statistical significance was determined at the 5% level and coefficients of variation (CV) given.

4.2.3 Results

Ambient greenhouse temperatures ranged from a night time low of 19^{o}C to an average day time high of 23^{o}C. The relative humidity ranged from an average night time high of 80% to a day time low of 63%.

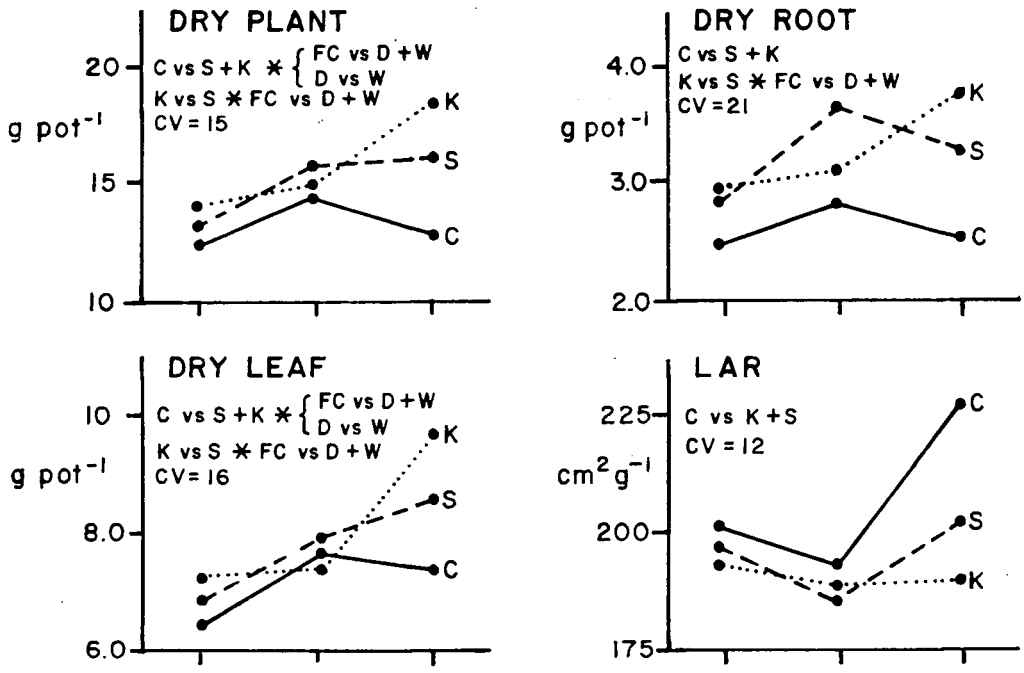
The analysis of variance F-values, MSE and mean values for each of the measured variables are presented in Appendices 21 - 26.

Harvest I: Figure 19 and Table 13 depict the significant growth and development effects for this harvest. The dry plant, root, leaf and stem plus leaf weights of the controls (C) were greatest in the field capacity (FC) soil treatment as compared to dry (D) and wet (W) soil moisture treatments. Both the E. maxima (K) and M. integrifolia (S) kelp foliar treatments increased each of these variables in the dry and wet soil moisture treatments with the greater increases occurring in the wet soil. Root weights were increased by the E. maxima treatment and M. integrifolia regardless of soil moisture treatment. The E. maxima foliar treatment increased root growth more in wet soils, while the M. integrifolia treatment increased plant root growth more on the field capacity soil. LAR was reduced by both the M. integrifolia and E. maxima kelp foliar spray treatments regardless of soil moisture treatments.

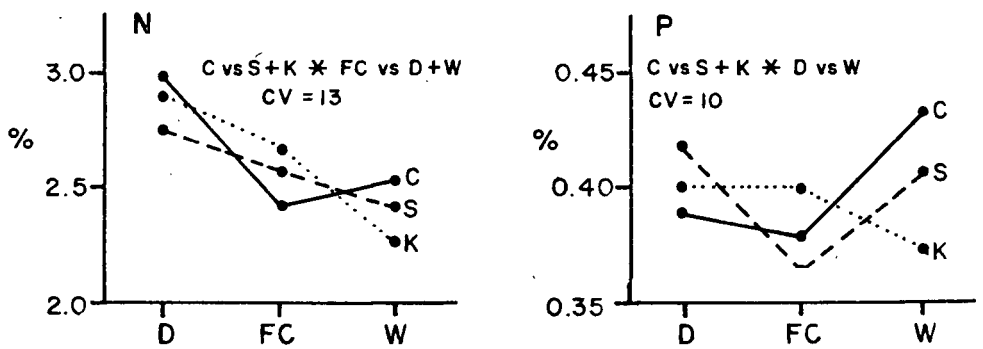
Control plants had higher N and P concentrations in the dry and wet soils relative to the field capacity soil (Figure 19). Both the E. maxima and M. integrifolia foliar treated plants had lower N concentrations on the dry and wet soils and increased N concentrations on field capacity soils. Kelp foliar sprays increased P concentration on dry soils, but reduced P concentration on wet soils. Shoot uptake of N,

HARVEST I

GROWTH, DEVELOPMENT AND NUTRITION



LEAF AND STEM ELEMENTAL CONCENTRATION



DAY 37

FOLIAR AND SOIL TREATMENT LEGEND: Foliar treatments include Control (C), M. integrifolia (S) and E. maxima (K). Soil moisture treatments include Dry (D), Field Capacity (FC) and Wet (W).

FIGURE 19.

Ca, Mg and Zn were increased by both kelp foliar sprays, regardless of the soil moisture treatments, with E. maxima treated plants having the greatest Ca and Mg uptake (Table 13).

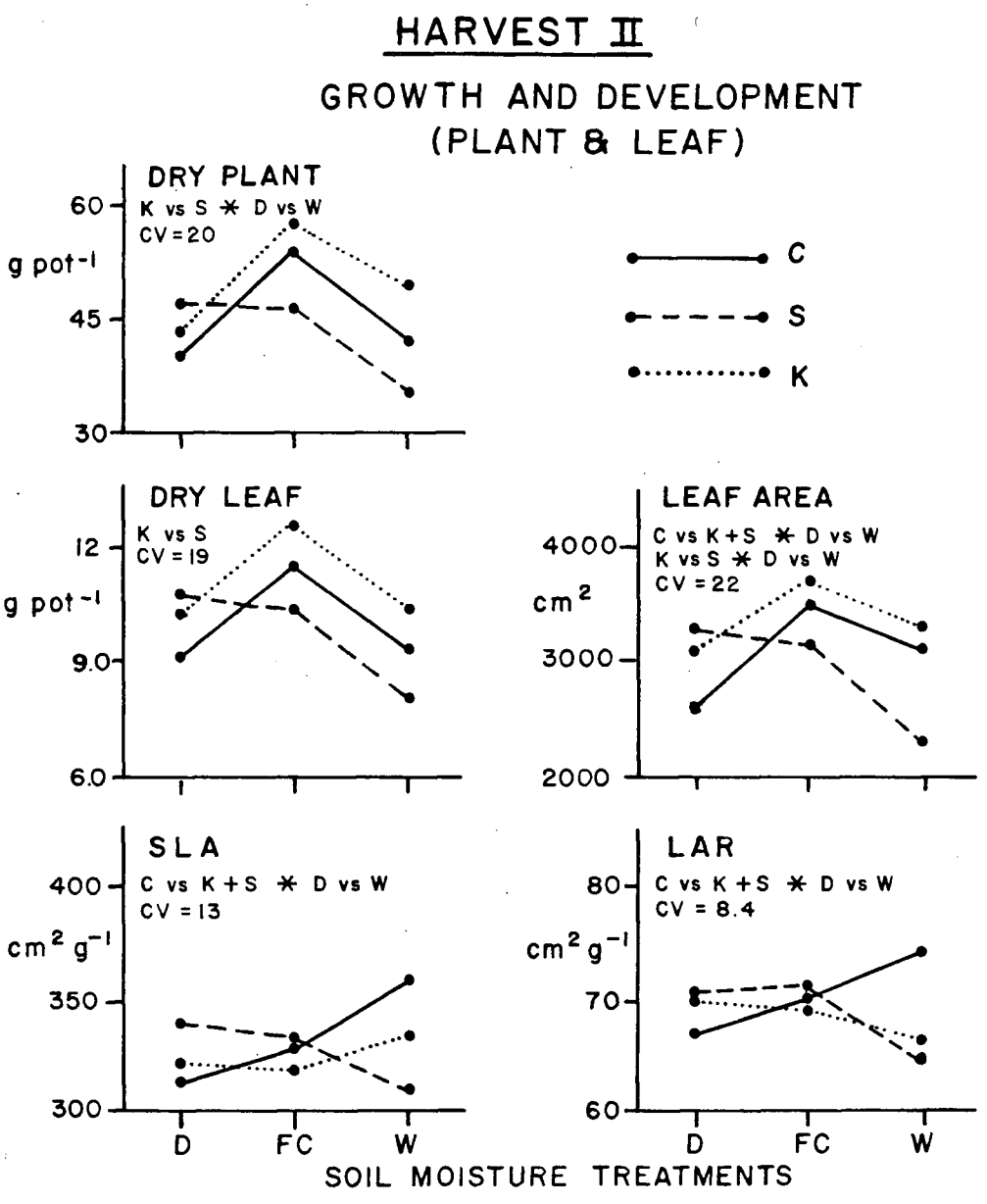
Harvest II: Significant growth and developmental responses for this harvest are depicted in Figures 20, 21 and 22. Control plants of field capacity soils had higher total, leaf, leaf and stem, bean pod and shoot weights and greater leaf area, number of beans and shoot/root ratios relative to the dry and wet soils. Control root weights, unlike in the first harvest, were greatest in the dry and wet soils, relative to field capacity soils. Control LAR, SLA, nodulation rating and node numbers increased as soil moisture treatments went from dry through field capacity to wet.

Figures 23, 24 and 25 illustrate the appearance of the plants just prior to the second harvest (Day 61) for dry, field capacity and wet soil moisture treatments, respectively. Plants which were treated with the the E. maxima kelp concentrate were visually greener or less senescent than the controls or M. integrifolia foliar treated plants for each of dry, field capacity and wet soil moisture treatments, although this greening effect was not as

TABLE 13. HARVEST I: SHOOT GROWTH AND ELEMENTAL UPTAKE

Kelp Foliar Traetments:	Control			*M. integrifolia*			*E. maxima*			Significant Contrasts	CV
Soil Moisture Treatments*:	D	FC	W	D	FC	W	D	FC	W		
Dry leaf & stem (g pot^{-1})	9.89	11.7	11.1	10.6	12.2	13.1	11.1	11.5	14.7	CvsS+K*FCvsD+W CvsS+K*DvsW	16
Leaf & Stem elemental uptake (mg pot^{-1})											
N	292	284	281	300	318	325	321	301	329	CvsS+K	15
Ca	130	150	160	140	160	180	150	170	230	CvsS+K; KvsS	22
Mg	41	46	51	43	49	56	46	53	68	CvsS+K; KvsS	21
Zn	0.31	0.41	0.53	0.36	0.43	0.61	0.36	0.45	0.70	CvsS+K	30

*Soil moisture treatments include Dry (D), Field Capacity (FC) and Wet (W).



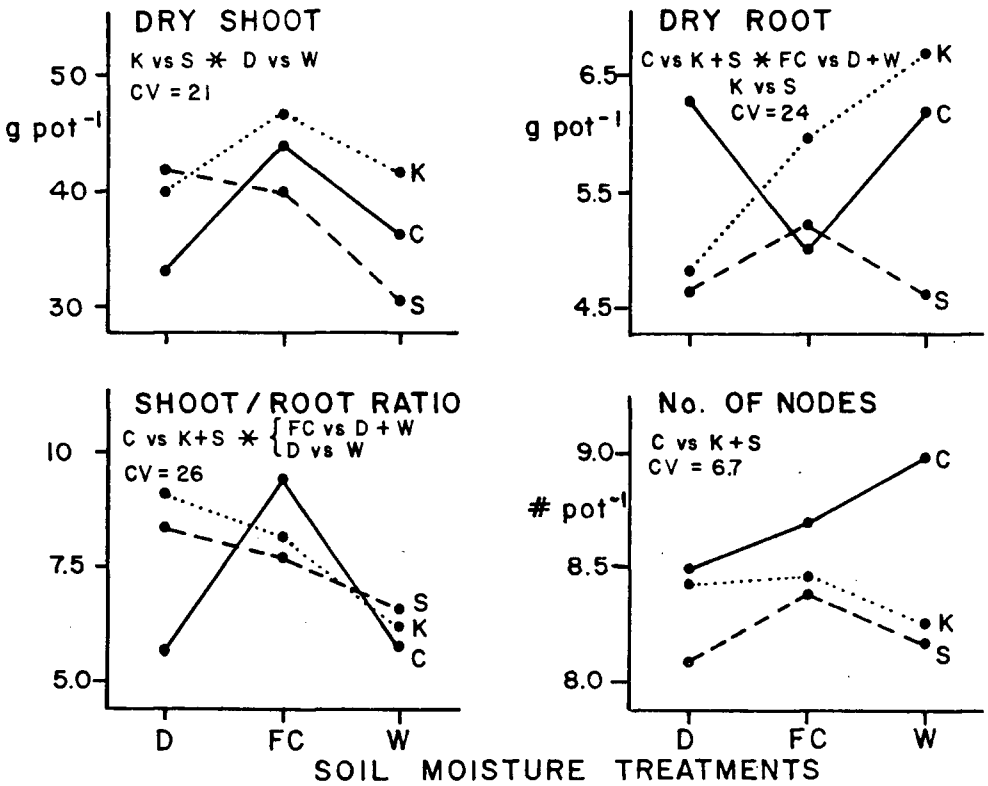
DAY 62

FOLIAR AND SOIL TREATMENT LEGEND: Foliar treatments include Control (C), M. integrifolia (S) and E. maxima (K). Soil moisture treatments include Dry (D), Field Capacity (FC) and Wet (W).

FIGURE 20

HARVEST II

GROWTH AND DEVELOPMENT
(SHOOT & ROOT)



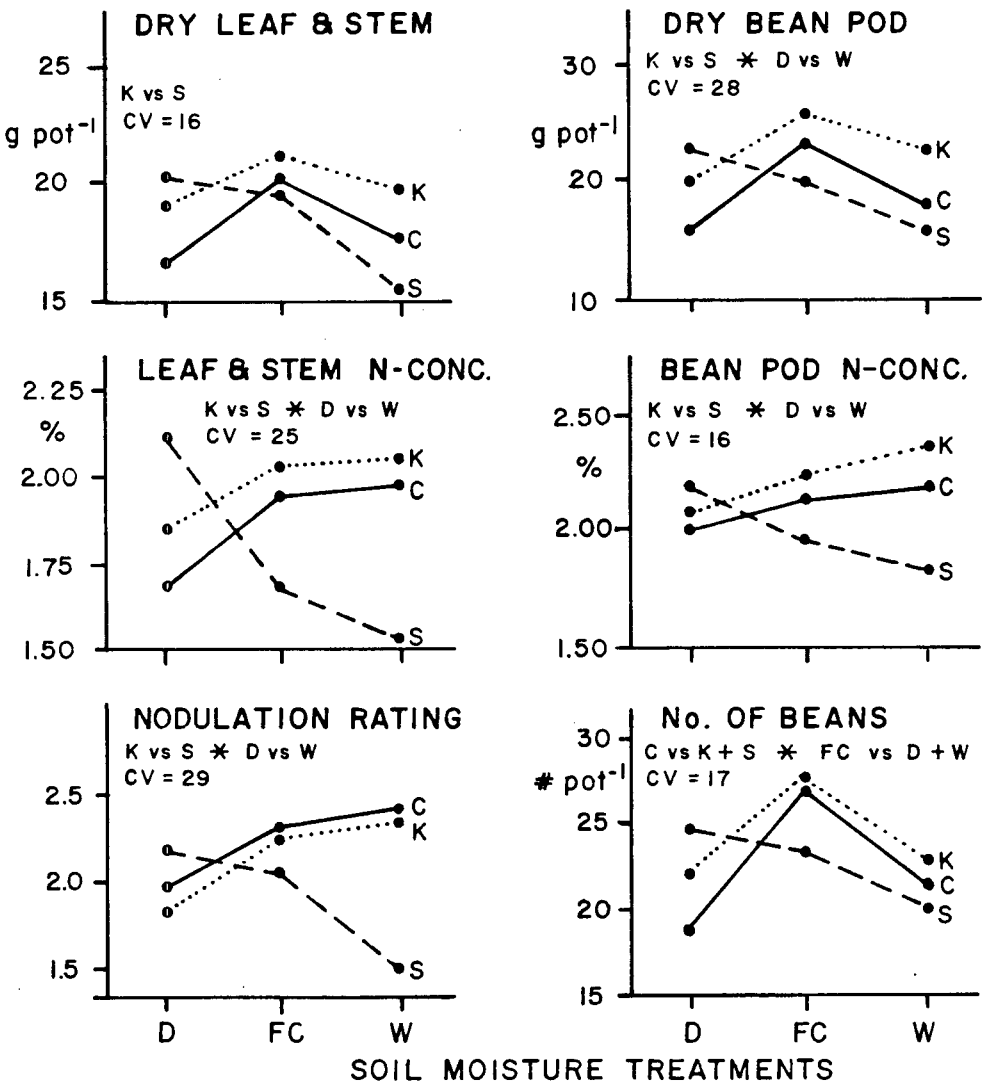
DAY 62

FOLIAR AND SOIL TREATMENT LEGEND: Foliar treatments include Control (C), M. integrifolia (S) and E. maxima (K). Soil moisture treatments include Dry (D), Field Capacity (FC) and Wet (W).

FIGURE 21

HARVEST II

GROWTH, DEVELOPMENT AND N-NUTRITION



DAY 62

FOLIAR AND SOIL TREATMENT LEGEND: Foliar treatments include Control (C), M. integrifolia (S) and E. maxima (K). Soil moisture treatments include Dry (D), Field Capacity (FC) and Wet (W).

FIGURE 22

HARVEST II BEAN PLANTS SUBJECTED TO
DRY SOIL MOISTURE TREATMENT
(DAY 62)

CONTROL (C) FOLIAR TREATMENT

M. integrifolia (S) FOLIAR TREATMENT

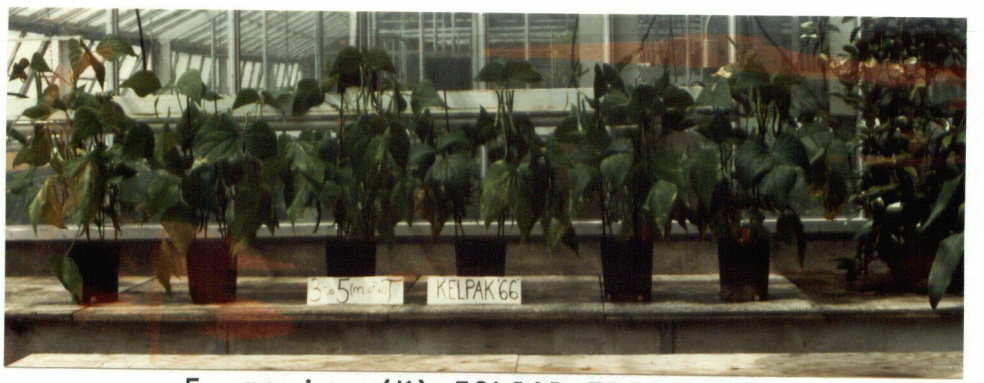
E. maxima (K) FOLIAR TREATMENT

FIGURE 23.

HARVEST II BEAN PLANTS SUBJECTED TO
FIELD CAPACITY SOIL MOISTURE TREATMENT
(DAY 62)

CONTROL (C) FOLIAR TREATMENT

M. integrifolia (S) FOLIAR TREATMENT



E. maxima (K) FOLIAR TREATMENT

FIGURE 24.

HARVEST II BEAN PLANTS SUBJECTED TO
WET SOIL MOISTURE TREATMENT
(DAY 62)

CONTROL (C) FOLIAR TREATMENT

M. integrifolia (S) FOLIAR TREATMENT

E. maxima (K) FOLIAR TREATMENT

FIGURE 25.

apparent with dry soils. Relative to the controls, plants which were foliar sprayed with the M. integrifolia kelp concentrate were greener in dry soils only and were very chlorotic or more senesced in wet soils.

At second harvest the E. maxima treated plants had the greatest total, leaf (Figure 20), shoot (Figure 21), combined leaf and stem and bean weights (Figure 22) and leaf areas (Figure 20) and bean numbers (Figure 22) in dry, field capacity and wet soils. The M. integrifolia foliar treatment increased these variables in the dry soil, but its effect on the field capacity soil was similar to that of the controls and less than the control in the wet soil treatment.

Relative to the controls, both the E. maxima and M. integrifolia kelp foliar treatments increased the LAR and SLA in dry soil and decreased these variables in wet soil (Figure 20). Shoot/root ratios of kelp treated plants were highest in dry soil but declined through field capacity to wet soil moisture treatments (Figure 21). Both kelp foliar sprays reduced the number of nodes, regardless of the soil moisture treatments (Figure 21). The E. maxima treated plants increased root growth from dry through field capacity to wet soil moisture treatments, whereas, the M.

integrifolia treated plants had the highest root growth in field capacity soils and lowest in dry and wet soil treatments.

Combined leaf and stem and bean pod N concentrations closely followed nodulation ratings (Figure 22). For both the control and E. maxima treated plants, nodulation and N concentrations were lowest in dry soils and highest with field capacity and wet soil moisture treatments, whereas M. integrifolia treated plants were highest in dry soils and declined through field capacity to wet soils. Combined leaf and stem and bean pod yields and bean numbers for M. integrifolia treated plants closely followed the same trends as for N concentrations and nodulation rating.

4.2.4 Discussion

Both the M. integrifolia (S) and E. maxima (K) kelp foliar sprays were effective in altering bean (P. vulgaris) growth, development and nutrition. However, major differences existed between the two kelp sprays with respect to efficacy under varying soil moisture regimes.

At the time when the dry (D) and wet (W) soil moisture treatments were removed (Harvest I), both of the kelp treatments were effective in increasing the plant and leaf weights of those plants which were subjected to dry and wet soil moisture treatments. Greater increases in total leaf and shoot weights with kelp treated plants subjected to wet, relative to the dry soil moisture treatment conditions, suggest that the plant physiological responses to the kelp foliar spray treatments were not equal between the wet and dry soil moisture treatments. The E. maxima foliar treatment was more effective than the M. integrifolia foliar treatment in increasing the total plant, root and leaf weights on the wet soil treatments, which could intimate growth regulating differences between the kelp foliar treatments themselves.

The lower LAR with kelp treated plants, regardless of the soil moisture treatments, suggests greater dry matter accumulation or net productivity per unit leaf area. Kelp foliar treated plants, regardless of the soil moisture treatments, increased root growth and N, Ca, Mg and Zn uptakes, which could also imply a greater supply of shoot photosynthates to enhance root growth and nutrient uptake.

According to Martin and Matocha (1973) the mineral composition of any plant is a result of the interaction of nutrient supply and plant growth. Therefore, any factor which limits growth, be it light, moisture, temperature or some nutrient may cause other nutrients to accumulate. In this investigation the higher elemental shoot N and P concentrations at first harvest with control plants subjected to the dry and wet soil moisture regimes, relative to the field capacity soil moisture regime, suggest that these elements had accumulated as yields declined. In contrast to the controls, shoot N concentrations of kelp treated plants were reduced on the dry and wet soil moisture treatments as yields were enhanced. Therefore, relative to the controls, the kelp treated plants may have undergone a so called "dilution effect" showing greater tolerance to the soil moisture stress as dry matter yields were enhanced. These results, particularly in the dry soil moisture regimes, support the theory that the enhanced growth and reduced elemental concentration effects of kelp foliar treatments in the 1983 and 1984 field trials (Section 4.1) may be dilution effects in response to greater dry matter accumulation or tolerance to the environmental growth conditions. Other

researchers (Blunden et. al., 1979; Nelson and van Staden, 1984a; Featonby-Smith and van Staden, 1987) have also reported a reduction in elemental N concentration with plants treated with kelp foliar sprays.

The effects of the kelp foliar treatments upon shoot P concentration at first harvest varied according to the soil moisture treatment. Relative to the controls, both the E. maxima and M. integrifolia kelp foliar treatments increased P concentrations on the dry soil and reduced P concentrations on the wet soil. Such a contrasting effect on P nutrition, with respect to soil moisture, demonstrated the influence of the particular growth environment on the type of nutritional response.

At second harvest, the E. maxima foliar treatment increased the total leaf, shoot and bean weights on both dry and wet soils. The M. integrifolia foliar treatment was only effective in increasing these growth variables on the dry soil moisture treatment. Relative to the control, the M. integrifolia treated plants, subjected to the wet soil moisture treatment, experienced rapid or accelerated senescence shortly after the third spraying. Growth responses included reduced leaf, stem, bean and root weights, and reduced leaf area and nodulation.

Nelson and van Staden (1984a) have also observed an initial inhibition of greenhouse cucumber during fruit set with E. maxima treatment. They suggest that inappropriate foliar applications during fruit set could have been responsible for the observed response, therefore, kelp foliar treatments should be timed to coincide with particular growth stages, rather than at regular time intervals throughout the growing period. Application of various known growth regulating substances at various stages and/or in combination at various stages of plant development is known to cause conflicting and opposite results and is a factor also controlling the effectiveness of these compounds (Kannan, 1980; Mishra and Gaur, 1985).

Finnie and van Staden (1985) have also demonstrated that the water dilution ratio of the E. maxima kelp concentrate to be an important factor controlling its efficacy. Low dilution ratios (1:100::kelp concentrate:water) can have an inhibitory effect upon root growth, whereas higher dilution ratios (1:400 to 1:600) can be stimulatory. These results could also suggest that the growth inhibitions, which were experienced with the M. integrifolia foliar treatment upon the wet soil, may have been related to a low water dilution of the concentrate. The fact that the 1:250 M. integrifolia

concentrate dilution was stimulatory on the dry soil treatment, yet inhibitory on the wet soil treatment, could also suggest that optimal dilution ratios of the concentrate may be dependent on the particular soil moisture regime or environmental conditions to which the plants are subjected. Such dilution effects could be attributed to growth inhibitors in the concentrate which, upon increasing dilution, become less effective than the growth promoting substances. Furthermore, the inhibition of root growth could also account for the loss of nodulation and the lowering of plant N concentration, as the supply of shoot photosynthates to support active nutrient uptake and N fixation may have diminished.

Although shoot and root yield responses to E. maxima and M. integrifolia foliar treatments differed markly among soil moisture treatments, their effects on plant shoot/root ratio, number of nodes, SLA and LAR were similar. Shoot/root ratios of both the E. maxima and M. integrifolia foliar treated plants declined from dry through field capacity to wet soil moisture treatments, whereas SLA and LAR remained relatively constant. Both the kelp foliar sprays were also effective in reducing the number of nodes, regardless of the soil moisture regimes. Although shoot and

root yield responses between the two kelp foliar sprays were quite different, the partitioning of photosynthates for dry matter accumulation and development was similar.

These growth, developmental and nutritional responses establish that, although there are some similarities between the two kelp foliar sprays, there are also some very apparent effective differences in relation to soil moisture environments. Finnie and van Staden (1985) postulated that several active constituents within the kelp concentrate may be implicated, some of which elicit different growth responses. Therefore, both qualitative and quantitative compositional differences with respect to suspected active components, such as cytokinins or other yet unidentified compounds, provide a plausible explanation for differing growth regulating effects which exist between the two kelp foliar concentrates of this investigation. Active constituent differences may be related to the different types of kelp utilized and/or the particular time or physiological age at which they were harvested and processed for subsequent use as a foliar spray.

In this investigation the endogenous levels of phytohormones may have been altered differently by the

various treatments. The ability of endogenous and exogenous phytohormones to regulate growth, photosynthate partitioning, long distance ion transport, mobilization of particular nutrients, and elemental concentration in plants is well documented (Fletcher et al, 1970; Adedipe et al, 1971: Salisbury and Ross, 1978; Marschner, 1982; Castro and Malavolta, 1983; Neumann and Stein, 1984). Therefore, the type of plant growth, developmental and nutritional responses to a kelp foliar treatment may be expected to interact with the endogenous levels of plant growth regulators, soil nutrient supply, weather conditions and with the concentration and/or timing of the kelp foliar treatment itself. Furthermore, the specific results of this greenhouse experiment could only pertain to the particular plant growth environment and foliar treatments described.

4.2.5 Conclusions

The plant growth, developmental and nutritional responses in this greenhouse experiment have demonstrated the effectiveness of two kelp, M. integrifolia and E. maxima, foliar sprays as plant growth regulating substances. Bean growth and mineral nutritional responses to the kelp, M. integrifolia and E. maxima, foliar spray treatments were

also dependent upon the particular soil moisture regime or environment to which they had been subjected. Although the two kelp foliar sprays had varying and sometimes contrasting effects on bean growth and elemental nutritional responses, which were dependent upon the soil moisture treatment, their developmental effects upon the number of nodes, shoot/root ratios, LAR and SLA were quite similar.

SUMMARY

Soil Amendment: The kelp, M. integrifolia, is one of the most concentrated organic sources of K. It is comparable to high quality barnyard manure in N concentration and much of the N is readily available in the soil as NO_3-N soon after application. This kelp is low in P and supplementary phosphate fertilizer may be necessary on P-deficient soils. The kelp M. integrifolia has a low C/N ratio; therefore, composting prior to its use as a soil amendment is not necessary. The kelp M. integrifolia, when used fresh as a soil amendment, will cause levels of soluble salts to increase in the soil surface horizon. No adverse effects upon bean crop growth were experienced with soil applications less than 60 t ha^{-1} fresh weight. Kelp applications greater than 60 t ha^{-1} and/or repeated applications in regions where rainfall is insufficient to leach the soil could cause a reduction in yields of crops sensitive to salt. Increased plant shoot moisture contents and Na, Cl and K concentrations and/or uptake with increasing kelp application were indicative of increasing levels of soil water-soluble salts. This kelp soil amendment increased soil NO_3-N, K, Mg and soil aeration, any of which may be beneficial to crop production.

Foliar Spray: In each of two field seasons four 2 and 4 L ha^{-1} applications of kelp concentrate, prepared from M. integrifolia, increased harvestable bean yields. A crude phytohormonal extract of this kelp concentrate was also effective in increasing marketable bean yields, although it was less effective than the pure concentrate itself. Mineral nutritional responses to kelp foliar treatment, relative to the controls, included greater uptake and reduced bean pod concentrations of several elements as yields increased (dilution effects). A subsequent greenhouse experiment demonstrated that some of the nutritional and growth responses to kelp foliar treatment may be dependent on soil moisture regimes. Plant developmental effects of kelp foliar treatment on shoot/root ratio, specific leaf area and leaf area ratio were also dependent on soil moisture treatment. Therefore, the effect of weather and/or climate on plant growth and development may be an important factor controlling the efficacy of kelp foliar treatments.

The results of these field and greenhouse investigations demonstrate the growth-regulating ability of a foliar applied M. integrifolia concentrate and its potential value to bean productivity. Research directed at a wider variety of crops under varying environmental conditions and kelp concentrate

water dilution ratios, timing and quantities of application and identification of active constituents is justified. Much more research will be required before any firm practical recommendation could be made for the use of kelp foliar sprays on a wide spectrum of crops.

Furthermore, these investigations exemplify the need for increased knowledge of the complex interactions between plant development and the environment and how plant growth regulating substances, such as those contained in kelp, could be used to benefit crop productivity. Plant-environment interactions are complex and generally not well understood. Relative crop growth increases occur in response to the alleviation of factor(s) which may be limiting growth. Kelp foliar applications could also supply growth-regulating substance(s) which, under particular environmental conditions, may be physiologically inappropriate. At particular times, application of some plant growth regulators may interfere with the plant's own adaptive strategy or regulation of growth in response to its environment. This lack of understanding of the plant growth-regulating substance(s) and the physiological effects that kelp foliar treatments are having on plant growth and development probably preclude its full acceptance into agricultural practice in the short term.

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APPENDIX 1. 1981 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR BEAN GROWTH RESPONSES.

Measured growth variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Emergence (% of two-leaf stage)													
Day 10	60.0**	1.75	0.55	90.0**	----	----	30.0**	67	b	b	b	67	17
Day 12	11.8**	2.12	1.19	17.7**	----	----	5.89*	75	b	b	b	75	42
Day 14	66.3**	0.33	0.25	112**	----	----	20.2**	100	b	b	b	95	62
Flowering (No. Plant^{-1})													
Day 40	6.57*	0.69	0.19	12.0*	----	----	1.14	1.3	b	b	b	0.47	0.22
Day 43	11.7**	1.25	1.38	23.0**	----	----	0.39	5.3	b	b	b	2.9	1.3
Day 45	13.0**	1.36	3.36	25.5**	----	----	0.50	10.0	b	b	b	7.6	3.5
Harvest plant yields (t ha^{-1})													
Fresh leaf and stem	1.64	0.25	18.5	3.35	4.83*	4.6E-3	1.2E-3	28.3	29.3	30.1	31.2	31.2	23.9
Fresh bean pod	4.40*	0.63	5.74	14.6**	7.21*	2.7E-3	0.11	16.5	16.3	17.2	17.7	17.1	10.9
Fresh shoot	2.45	0.37	44.3	6.53*	5.69*	6.43-4	1.3E-2	44.8	45.6	47.3	49.0	48.3	34.8
Dry leaf and stem	2.39	0.81	0.49	8.39*	3.16	9.7E-2	0.18	4.72	4.79	4.78	5.13	4.71	3.55
Dry bean pod	4.17*	1.69	5.5E-2	15.5**	4.83*	0.10	0.17	1.56	1.49	1.59	1.58	1.55	0.97
Dry shoot	3.04*	1.00	0.79	11.0**	3.93	2.6E-2	0.12	6.28	6.29	6.36	6.71	6.26	4.52
Harvest index (%)													
Fresh	12.6**	1.88	1.5E-4	55.1**	5.72*	0.38	1.03	36.9	35.6	36.5	36.2	35.4	31.0
Dry	1.65	1.16	5.8E-4	5.55*	1.07	0.61	0.52	25.0	23.7	25.1	23.7	24.7	20.9
Fresh/dry weight ratios													
Leaf and stem	2.86	2.12	0.12	11.9**	0.58	0.23	0.76	6.00	6.15	6.29	6.14	6.63	6.75
Bean pod	0.64	2.14	0.80	2.54	5.3E-2	0.41	0.10	10.6	11.0	10.9	11.2	11.1	11.6
Shoot	2.12	2.53	0.11	7.89*	1.43	0.14	0.59	7.13	7.28	7.42	7.32	7.73	7.72

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error.
[b] Not sampled.

APPENDIX 2. 1982 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR PEA GROWTH RESPONSES.

Measured growth variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Emergence (% two leaf stage)													
Day 13	1.65	1.65	2.56	0.95	2.35	---	1.63	32	b	b	30	45	20
Day 15	0.83	0.83	2.00	0.70	1.43	---	0.36	82	b	b	92	87	77
Harvest plant yields (t ha^{-1})													
Fresh leaf & stem	1.31	4.37*	6.57	4.41	0.72	0.29	0.55	20.8	19.5	19.2	20.6	19.7	16.7
Fresh pod	0.35	1.04	16.0	0.50	0.25	2.1E-3	0.51	23.3	24.5	21.5	23.0	21.5	21.9
Fresh pea	0.42	1.11	3.40	0.30	0.33	6.5E-2	0.70	11.0	12.0	10.4	11.1	10.3	10.8
Fresh shoot	0.72	1.25	27.4	2.56	7.5E-4	5.3E-2	0.54	44.2	43.9	40.6	43.6	41.2	38.6
Dry leaf and stem	1.78	2.23	0.11	6.41*	1.49	1.2E-2	0.49	3.29	3.11	3.26	3.25	3.16	2.71
Dry pod	0.27	1.62	0.35	6.6E-3	0.46	0.24	0.32	3.73	3.93	3.62	3.82	3.52	3.87
Dry pea	0.47	1.25	0.13	0.37	0.67	0.29	0.51	2.35	2.53	2.28	2.36	2.15	2.31
Dry shoot	0.44	0.74	0.46	1.47	3.8E-4	0.23	0.25	7.02	7.04	6.88	7.16	6.68	6.57
Harvest index (%)													
Fresh pod	0.56	2.36	3.2E-3	0.86	0.89	1.6E-2	0.53	52.8	55.6	51.4	52.8	52.2	56.9
Fresh pea	0.81	3.43*	8.8E-4	1.45	0.97	0.25	0.68	25.0	27.3	25.3	25.5	25.2	28.2
Dry pod	0.88	2.31	2.9E-3	2.12	1.27	2.1E-2	0.50	53.1	55.6	51.7	53.2	52.7	58.7
Dry pea	0.58	2.08	1.3E-3	7.8E-2	1.34	6.2E-2	0.71	33.5	35.9	32.7	33.0	32.3	35.1
Fresh/dry weight ratios													
Leaf & stem	1.03	4.79*	0. 10	1.5E-2	0.24	2.53	1.19	6.34	5.25	5.86	6.12	6.22	6.15
Pod	1.09	1.74	0.18	2.36	1.8E-3	1.44	0.82	6.26	6.25	5.79	6.04	6.09	5.73
Pea	0.54	2.11	6.6E-2	0.19	8.6E-2	0.92	0.75	4.70	4.75	4.51	4.69	4.79	4.71
Shoot	1.10	3.34*	0.12	1.33	1.5E-3	2.08	1.05	6.30	6.24	5.83	6.09	6.16	5.90

*,** Significant at 5% and 1% level, significantly.
[a] Mean square error.
[b] Not sampled.

APPENDIX 3. 1981 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR BEAN ELEMENTAL CONCENTRATIONS.

Measured concentration variables	Source F-values: Treatment	Block	[a]MSE	Curvilinear F-values: Linear	Quadratic	Cubic	Residual	Mean values: Kelp Application t ha^{-1} 0	7.5	15	30	60	120
Flowering (Trifoliate)													
N%	0.91	2.04	4.8E-2	0.71	3.1E-3	----	2.01	4.54	b	b	4.68	4.44	4.47
P%	0.24	0.25	6.65E-2	2.20	0.14	----	0.38	0.30	b	b	0.31	0.30	0.30
K%	4.46*	1.01	8.9E-2	9.95*	3.1E-2	----	3.39	3.3	b	b	3.2	3.7	3.8
Ca%	1.23	0.51	4.6E-2	0.76	0.19	----	2.76	1.8	b	b	1.6	1.8	1.6
Mg%	0.92	0.17	8.9E-4	6.4E-2	0.99	----	1.71	0.32	b	b	0.28	0.30	0.30
Cl%	9.08**	1.47	2.0E-2	25.7**	1.47	----	8.3E-2	0.88	b	b	1.10	1.20	1.40
Na mg kg^{-1}	3.00	3.71	1024	8.82*	3.5E-2	----	0.13	140	b	b	160	180	210
Fe mg kg^{-1}	1.22	1.87	1561	2.60	0.36	----	0.69	220	b	b	240	220	270
Mn mg kg^{-1}	2.73	1.26	242	6.35*	4.4E-2	----	1.79	35	b	b	54	47	66
Zn mg kg^{-1}	0.97	0.48	25.0	0.50	2.14	----	0.26	34	b	b	36	40	36
Al mg kg^{-1}	1.64	3.19	4856	0.81	8.5E-3	----	4.10	260	b	b	340	260	330
Harvest (leaf & stem)													
N%	2.51	0.71	3.4E-2	9.61**	0.62	1.20	0.57	2.84	2.75	2.83	2.71	2.95	3.12
P%	1.20	1.93	2.1E-4	4.80*	0.29	0.38	0.26	0.23	0.24	0.23	0.23	0.24	0.25
K%	14.6**	7.3E-2	4.4E-2	55.4**	7.51*	3.33	3.43	2.4	3.3	2.7	2.6	3.2	3.2
Ca%	0.65	0.86	0.10	0.10	0.12	3.7E-2	1.51	1.9	1.6	1.8	1.9	1.8	1.7
Mg%	0.88	1.05	1.8E-3	1.5E-2	0.42	4.3E-2	1.97	0.34	0.31	0.37	0.34	0.35	0.33
Cl%	3.31*	1.74	9.6E-2	12.4**	0.89	1.66	0.75	0.88	1.30	1.30	1.40	1.50	1.70
Na mg kg^{-1}	1.14	4.45*	694	3.15	0.41	0.31	0.91	160	140	160	160	170	170
Fe mg kg^{-1}	2.97*	1.70	1166	7.80*	0.22	1.7E-2	3.40	180	180	220	170	210	240
Mn mg kg^{-1}	1.20	0.61	269	3.93	9.4E-2	0.95	0.52	47	50	63	54	55	72
Zn mg kg^{-1}	1.43	2.34	13.2	4.54*	6.3E-2	5.4E-4	1.29	36	36	40	37	40	41
Al mg kg^{-1}	2.29	1.63	1862	4.75*	7.1E-2	1.1E-2	3.32	210	210	260	200	250	270
Harvest (bean pod)													
N%	1.26	0.60	2.8E-2	5.78*	0.16	0.17	9.2E-2	2.71	2.77	2.82	2.82	2.88	2.98
P%	0.29	1.04	5.9E-4	1.2E-2	4.8E-7	0.82	0.32	0.35	0.36	0.35	0.36	0.35	0.35
K%	1.52	2.17	8.9E-2	0.91	0.12	4.14	1.22	2.3	2.4	2.4	2.7	2.3	2.6
Ca%	0.84	0.93	2.7E-3	4.1E-3	6.2E-2	1.78	1.18	0.36	0.39	0.36	0.42	0.36	0.38
Mg%	1.48	1.68	5.2E-4	0.89	0.51	4.50	0.74	0.21	0.21	0.21	0.23	0.18	0.20
Na mg kg^{-1}	Below detection limit												
Fe mg kg^{-1}	1.37	2.46	173	0.36	1.55	0.65	2.13	92	72	75	82	77	87
Mn mg kg^{-1}	2.86	0.82	19.2	11.1**	0.54	2.15	0.22	21	21	24	24	23	31
Zn mg kg^{-1}	2.04	2.07	4.87	8.71**	0.10	0.83	0.28	30	30	32	32	32	35
Al mg kg^{-1}	2.91*	6.02**	75.5	0.11	1.28	1.60	5.77*	27	15	25	37	22	22

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error.
[b] Not sampled.

APPENDIX 4. 1981 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR BEAN ELEMENTAL UPTAKE.

Measured uptake variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Harvest (leaf & stem)													
N kg ha^{-1}	0.76	0.93	5.94	2.20	1.48	2.7E-2	9.3E-3	134	134	135	139	139	111
P kg ha^{-1}	1.64	1.81	2.63	4.44	2.94	5.7E-6	0.41	11	11	11	12	11	9
K kg ha^{-1}	2.29	0.96	417	0.14	10.0**	0.40	0.43	110	110	130	130	150	110
Ca kg ha^{-1}	1.68	1.20	349	3.80	1.97	0.13	1.25	89	76	87	98	83	63
Mg kg ha^{-1}	1.34	0.73	14.0	3.76	2.11	8.5E-2	0.36	16	15	18	18	17	12
Cl kg ha^{-1}	1.26	0.55	338	0.63	3.74	1.37	0.28	42	62	61	72	69	61
Na g ha^{-1}	1.46	2.50	1.9E-4	0.68	4.42	2.3E-2	1.09	730	630	780	800	810	620
Fe g ha^{-1}	0.39	1.10	8.5E-4	5.4E-3	0.45	1.5E-2	0.73	850	890	1100	870	1000	880
Mn g ha^{-1}	0.32	0.12	1.1E-4	1.0E-4	0.36	0.78	0.24	220	240	310	280	260	250
Zn g ha^{-1}	0.76	1.29	1.42	1.51	2.08	3.5E-2	9.5E-2	170	170	190	190	190	150
Al g ha^{-1}	0.44	0.98	1.3E-6	6.1E-2	0.53	1.5E-2	0.80	980	1100	1300	1000	1200	1000
Harvest (bean pod)													
N kg ha^{-1}	2.95*	2.21	51.6	9.20**	5.27*	2.1E-2	0.12	42.4	41.6	44.9	44.8	44.7	30.0
P kg ha^{-1}	4.03*	2.42	0.75	15.2**	4.69*	1.9E-2	9.6E-2	5.4	5.4	5.6	5.8	5.4	3.4
K kg ha^{-1}	3.33*	5.01*	41.2	10.0**	3.48	1.47	0.82	37	36	38	43	35	25
Ca kg ha^{-1}	4.30*	3.75*	1.00	14.1**	4.75*	0.82	0.89	5.8	5.7	5.8	6.8	5.5	3.6
Mg kg ha^{-1}	5.05**	4.68*	0.25	19.5**	2.37	1.56	0.91	3.3	3.1	3.4	3.6	2.8	2.0
Na	Concentration below detection.												
Fe g ha^{-1}	2.52	4.30*	713	7.74*	0.41	0.88	1.79	150	110	120	130	120	84
Mn g ha^{-1}	0.69	1.00	78.6	0.51	1.41	0.82	0.36	32	32	39	39	35	30
Zn g ha^{-1}	3.28*	3.53*	57.4	9.16**	6.51*	7.3E-3	0.37	48	46	51	52	50	33
Al g ha^{-1}	3.71*	6.23**	201	2.71	3.23	1.50	5.56*	43	24	40	60	35	24
Harvest (shoot)													
N kg ha^{-1}	1.32	1.37	840	4.00	2.53	3.0E-2	1.7E-2	176	175	180	184	184	140
P kg ha^{-1}	2.86	2.42	4.94	9.36**	4.39	3.1E-3	0.27	16	17	16	18	17.8	12
K kg ha^{-1}	2.66	2.14	489	0.31	12.0**	5.6E-2	0.43	150	150	170	170	180	140
Ca kg ha^{-1}	1.86	1.33	367	4.40	2.19	0.15	1.28	95	82	93	105	89	67
Mg kg ha^{-1}	1.99	1.14	14.6	6.16*	2.64	0.20	0.48	20	18	21	21	19	14
Fe g ha^{-1}	0.35	1.25	9.5E-4	9.6E-2	0.48	1.3E-3	0.60	990	1000	1200	1000	1100	960
Mn g ha^{-1}	0.34	9.5E-2	1.3E-4	4.2E-3	0.42	0.79	0.24	260	270	350	320	290	280
Zn g ha^{-1}	1.22	1.84	1760	2.73	3.09	3.4E-2	0.14	220	220	240	240	240	180
Al g ha^{-1}	0.43	1.06	1.3E-6	9.7E-2	0.63	2.9E-2	0.71	1000	1100	1300	1100	1200	1000

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error.

APPENDIX 5. 1982 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR PEA ELEMENTAL CONCENTRATIONS.

Measured concentration variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Flowering (leaf & stem)													
N%	1.05	5.10*	0.15	2.49	1.43	4.3E-2	0.23	3.54	b	3.48	3.65	3.59	3.13
P%	2.43	2.83	7.1E-4	3.98	1.57	2.95	1.25	0.30	b	0.31	0.34	0.30	0.28
K%	2.02	2.15	8.4E-2	1.59	5.80*	0.69	1.2E-2	2.9	b	3.0	3.1	3.5	3.1
Ca%	0.68	0.82	6.5E-3	0.44	1.48	0.36	0.48	1.0	b	1.1	1.0	1.1	1.0
Mg%	0.76	1.88	8.1E-4	0.29	2.4E-2	0.14	2.59	0.28	b	0.31	0.28	0.29	0.30
Na mg kg^{-1}	2.58	13.9*	4218	6.68*	0.26	5.8E-3	3.37	560	b	520	620	610	650
Fe mg kg^{-1}	1.25	1.71	6723	0.55	6.6E-2	3.31	1.09	180	b	240	210	150	190
Mn mg kg^{-1}	0.86	2.48	147	1.8E-2	8.8E-2	1.87	1.47	25	b	39	29	25	32
Zn mg kg^{-1}	0.48	1.16	91.6	5.3E-2	8.8E-2	0.67	1.10	42	b	51	45	46	47
Al mg kg^{-1}	1.13	1.66	1.4E-4	0.28	1.2E-2	2.81	1.41	62	b	75	72	52	95
Harvest (leaf & stem)													
N%	1.37	1.12	9.8E-2	8.2E-2	3.2E-6	0.70	3.04	2.59	2.70	2.17	2.62	2.55	2.47
P%	1.33	1.29	6.1E-4	1.6E-2	0.64	0.62	2.70	0.20	0.20	0.16	0.19	0.18	0.19
K%	2.12	1.71	0.12	6.46*	0.57	0.17	1.69	2.8	3.2	2.8	3.1	3.3	3.4
Ca%	1.81	0.64	1.1E-2	9.6E-2	1.04	3.97	1.98	0.9	1.2	1.1	1.1	1.1	1.1
Mg%	0.46	1.02	1.6E-2	0.44	3.4E-2	1.00	0.41	0.16	0.19	0.20	0.18	0.18	0.20
Na mg kg^{-1}	6.89**	6.86**	8305	23.8**	5.88*	4.2E-2	2.36	900	850	920	1100	1100	1100
Fe mg kg^{-1}	1.10	0.62	2.5E-4	4.41	0.52	1.0E-2	0.28	390	440	380	300	265	220
Mn mg kg^{-1}	0.95	1.89	204	1.43	0.55	0.80	0.97	28	27	40	28	28	42
Zn mg kg^{-1}	1.15	1.64	102	1.98	0.72	2.45	0.81	45	52	55	48	48	59
Al mg kg^{-1}	0.69	0.41	4.0E-4	3.04	0.21	0.19	7.3E-3	570	510	490	430	420	330
Harvest (pod)													
N%	0.50	1.07	8.8E-2	0.52	2.0E-2	0.30	0.82	4.40	4.33	4.17	4.44	4.42	4.44
P%	1.70	0.95	2.3E-4	2.00	0.22	0.92	2.69	0.40	0.38	0.40	0.41	0.40	0.41
K%	1.39	1.68	2.3E-2	2.81	5.5E-2	9.2E-2	2.00	1.3	1.4	1.4	1.2	1.4	1.5
Ca mg kg^{-1}	2.75	3.11	1.30E-4	2.20	0.14	3.41	4.00*	750	890	690	660	820	660
Mg%	1.79	1.61	1.8E-4	2.3E-4	0.26	2.1	3.26	0.13	0.15	0.13	0.13	0.15	0.14
Na mg kg^{-1}	1.01	1.74	1012	0.40	1.53	0.44	1.34	140	170	140	140	170	130
Fe mg kg^{-1}	0.16	4.7E-2	87.5	0.15	0.19	0.30	7.3E-2	62	60	60	62	65	62
Mn mg kg^{-1}	1.70	1.32	3.04	4.86*	1.65	1.57	0.2	12	13	14	13	13	16
Zn mg kg^{-1}	0.59	0.69	2.47	0.59	1.01	8.5E-2	0.64	27	29	28	28	29	28
Al mg kg^{-1}	0.40	0.45	255	0.29	0.18	1.05	0.25	17	10	12	12	12	7

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error.
[b] Not sampled.

APPENDIX 6. 1982 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR PEA ELEMENTAL UPTAKE.

Measured uptake variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Harvest (leaf & stem)													
N kg ha^{-1}	1.43	2.76	177	2.86	0.68	0.35	1.64	85.1	83.8	71.4	87.5	81.3	67.8
P kg ha^{-1}	1.42	3.24	0.90	2.89	9.5E-3	0.35	1.92	6.4	6.1	5.2	6.3	5.7	5.1
K kg ha^{-1}	0.58	2.37	277	9.1E-4	1.99	4.0E-2	0.45	92	99	91	100	100	92
Ca kg ha^{-1}	1.65	0.41	28.3	2.88	2.63	1.98	0.39	32	36	35	39	34	29
Mg kg ha^{-1}	0.43	7.8E-2	1.75	0.63	0.20	1.10	0.12	5.5	6.1	6.5	6.2	5.6	5.4
Na g ha^{-1}	1.89	5.30*	0.28	0.68	5.39*	7.6E-2	1.66	3.0	2.7	3.0	3.7	3.5	3.1
Fe g ha^{-1}	1.40	1.05	2.6E-5	6.33*	0.27	2.1E-2	0.19	1300	1400	1200	1000	840	600
Mn g ha^{-1}	0.63	1.20	1846	9.4E-2	0.15	0.88	1.00	93	86	130	94	87	110
Zn g ha^{-1}	0.56	0.56	953	0.11	1.4E-2	1.73	0.47	150	160	180	160	150	160
Al g ha^{-1}	1.02	0.84	4.2E-5	4.84*	3.9E-2	0.16	2.9E-2	1900	1600	1600	1500	1300	900
Harvest (pod)													
N kg ha^{-1}	0.24	1.91	833	5.5E-2	0.20	0.11	0.42	163	170	154	170	160	170
P kg ha^{-1}	0.29	1.54	5.95	0.14	0.25	0.52	0.28	15	15	15	16	14	16
K kg ha^{-1}	0.71	0.54	83.7	1.46	0.31	1.8E-2	0.88	47	55	49	48	51	56
Ca kg ha^{-1}	1.26	0.29	0.46	0.99	9.3E-2	0.57	2.34	2.8	3.5	2.5	2.5	2.8	2.5
Mg kg ha^{-1}	0.64	0.46	1.08	5.4E-4	0.10	8.8E-2	1.50	5.0	6.0	4.8	5.0	5.3	5.3
Na g ha^{-1}	0.79	0.63	1.6E4	0.32	0.24	0.12	1.64	510	550	530	520	590	510
Fe g ha^{-1}	0.15	0.87	2355	8.6E-2	9.5E-2	1.1E-2	0.28	230	240	220	240	220	240
Mn g ha^{-1}	1.62	2.55	82.2	3.72	2.39	1.33	0.33	47	52	48	51	45	61
Zn g ha^{-1}	0.26	1.21	343	6.0E-2	7.9E-2	0.17	0.49	100	110	100	100	100	110
Al g ha^{-1}	0.39	0.45	3412	0.35	0.31	0.92	0.18	46	59	44	42	51	28
Harvest (shoot)													
N kg ha^{-1}	0.42	0.94	1367	0.17	4.6E-3	3.3E-3	0.96	249	254	226	258	238	238
P kg ha^{-1}	0.39	0.95	8.50	5.5E-2	0.15	0.16	0.80	21	21	20	22	20	21
K kg ha^{-1}	0.47	1.00	416	0.26	0.80	1.0E-2	0.65	140	150	140	150	150	150
Ca kg ha^{-1}	1.70	0.39	29.1	3.24	2.43	1.67	0.58	35	40	38	41	37	32
Mg kg ha^{-1}	0.75	0.47	1.74	0.60	3.5E-2	0.66	1.22	10	12	11	11	11	11
Na kg ha^{-1}	1.57	5.26*	0.31	0.42	5.39*	3.3E-2	1.00	3.5	3.3	3.5	4.2	4.1	3.6
Fe g ha^{-1}	1.30	0.84	2.8E5	5.85*	0.28	2.3E-2	0.17	1500	1600	1500	1200	1100	840
Mn g ha^{-1}	0.76	1.34	1943	0.48	0.50	1.33	0.74	140	140	180	140	130	170
Zn g ha^{-1}	0.74	0.43	838	4.2E-2	9.5E-2	2.79	0.38	250	270	280	270	250	270
Al g ha^{-1}	1.08	0.94	4.2E5	5.03*	0.61	0.23	3.6E-2	1900	1700	1600	1500	1400	980

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error.

APPENDIX 7. 1981 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR SOIL CHEMICAL PROPERTIES.

Measured soil variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Preseeding 1981:													
NO_3-N (mg kg^{-1})	10.5*	0.42	215	20.7**	---	---	0.23	31	b	b	b	50	78
NH_4-N (mg kg^{-1})	2.28	1.87	16.6	2.43	---	---	2.13	3.9	b	b	b	9.8	8.4
NO_3 + NH_4-N (mg kg^{-1})	20.1**	0.70	146	40.3**	---	---	1.3E-2	35	b	b	b	60	86
pH (2:1 water:soil)	6.67*	2.24	6.7E-2	7.46*	---	---	5.89	5.7	b	b	b	5.1	5.2
Soluble Cl (mg kg^{-1})	7.67*	0.20	2.5E5	15.1**	---	---	0.24	140	b	b	b	1000	1600
EC: (dS m^{-1})	10.3*	0.12	0.36	20.2**	---	---	0.45	0.48	b	b	b	1.7	2.4
Harvest 1981:													
NO_3-N (mg kg^{-1})	4.33*	1.19	30.1	12.0**	7.72*	0.12	0.86	19	21	22	31	32	31
NH_4-N (mg kg^{-1})	4.08*	5.92**	1.25	14.9**	3.87	1.02	0.29	3.7	4.4	4.0	4.1	3.9	6.7
NO_3 + NH_4-N	4.32*	1.46	35.6	15.2**	4.70*	0.26	0.71	23	25	26	35	36	38
pH (2:1 water:soil)	2.54	2.76	0.10	11.0**	0.15	1.50	1.2E-2	5.2	5.0	5.0	4.9	4.9	4.4
Soluble Cl (mg kg^{-1})	15.7**	1.56	9723	71.6**	3.04	3.70	0.22	260	390	430	560	600	820
EC (dS m^{-1})	47.9**	1.09	9.4E-3	238**	0.14	0.28	0.32	0.52	0.60	0.63	0.80	0.98	1.40
Available P (mg kg^{-1})	1.32	9.82**	84.7	3.48	1.35	1.78	1.1E-2	71	77	80	85	82	86
Exchangeables (cmol^{+} kg^{-1}):													
Ca	0.24	0.43	0.89	0.68	0.10	0.24	9.5E-2	7.5	7.5	7.0	7.5	7.5	7.0
Mg	4.87**	5.40*	5.5E-3	21.6**	1.17	0.68	0.45	1.5	1.5	1.5	1.5	1.6	1.7
K	55.2**	0.91	1.0E-2	266**	6.53*	0.19	1.25	0.85	0.83	0.95	0.93	1.2	1.6
Na	57.8**	5.40*	3.1E-2	284**	1.20	4.3E-3	1.73	0.30	0.36	0.35	0.50	0.61	0.87
Mn	2.93*	9.05**	0.67	12.4**	9.0E-2	9.3E-2	1.04	0.045	0.044	0.048	0.048	0.055	0.060

*,**Significant at 5% and 1% level, respectively.
[a]Mean square error.
[b]Not sampled.

APPENDIX 8. 1982 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED [a]MSE, MEANS AND F-VALUES FOR SOIL CHEMICAL PROPERTIES.

Measured soil variables	Source F-values			Curvilinear F-values				Mean values					
								Kelp Application t ha^{-1}					
	Treatment	Block	[a]MSE	Linear	Quadratic	Cubic	Residual	0	7.5	15	30	60	120
Preseeding 1982:													
NO_3-N (mg kg^{-1})	2.41	2.03	2.50	8.78**	2.84	5.0E-3	0.22	18	18	17	17	18	21
NH_4-N (mg kg^{-1})	1.83	8.50**	1.03	2.06	1.26	5.43*	0.19	3.9	2.6	2.3	1.9	2.7	2.2
NO_3 + NH_4-N (mg kg^{-1})	1.57	6.41**	3.57	2.83	3.66	1.12	0.13	22	21	19	20	20	23
pH (2:1 water:soil)	1.67	0.34	0.19	0.57	0.56	4.40	1.85	5.4	4.6	5.2	4.9	5.7	5.1
Soluble Cl (mg kg^{-1})	6.67**	1.93	314	12.9**	0.95	3.56	8.20**	210	190	170	220	220	230
EC (dS m^{-1})	3.69*	3.54*	9.7E-4	14.2**	3.1E-2	3.22	0.48	0.31	0.34	0.33	0.36	0.34	0.40
Available P (mg kg^{-1})	8.7E-2	5.08*	1.61	1.9E-2	1.5E-2	0.10	0.15	73	75	72	78	74	75
Exchangeables (cmol$^+$ kg^{-1})													
Ca	0.78	0.39	1.44	2.59	1.8E-3	0.15	0.58	6.5	7.0	6.5	6.5	6.0	6.0
Mg	0.62	4.7E-2	3.9E-2	2.1E-3	1.88	0.89	0.15	1.2	1.3	1.3	1.2	1.1	1.3
K	18.9**	0.77	2.3E-2	87.0**	6.04*	0.55	0.55	0.73	0.87	0.83	0.85	1.0	1.6
Na	16.8**	9.73**	4.0E-4	73.6**	3.00	1.79	2.77	0.21	0.20	0.19	0.24	0.27	0.29
Mn	5.93**	17.9**	0.27	13.5**	2.0E-2	5.17*	2.65	0.045	0.039	0.044	0.048	0.050	0.055
Harvest 1982:													
NO_3-N (mg kg^{-1})	0.61	1.65	4.46	0.22	6.4E-2	1.56	0.60	17	18	17	19	17	18
NH_4-N (mg kg^{-1})	1.06	12.8**	4.35	2.53	8.1E-2	2.63	3.1E-2	5.4	6.5	7.1	6.8	4.8	4.6
NO_3 + NH_4-N (mg kg^{-1})	2.14	3.92*	8.01	7.4E-2	0.59	5.36*	2.35	22	24	24	26	22	23
pH (2:1 water:soil)	0.20	0.27	0.15	0.37	0.57	7.6E-3	3.9E-2	5.1	5.1	5.0	5.0	4.9	5.0
Soluble Cl (mg kg^{-1})	0.86	0.70	790	0.12	0.46	2.5E-2	1.84	220	180	210	200	190	200
EC (dS m^{-1})	0.78	1.53	1.7E-3	0.86	1.0E-2	0.22	1.41	0.32	0.29	0.30	0.34	0.31	0.33
Available P (mg kg^{-1})	0.63	8.62**	108	0.17	3.1E-2	0.60	1.18	68	75	80	71	74	76
Exchangeables (cmol$^+$ kg^{-1})													
Ca	1.64	0.54	0.89	0.92	2.30	2.30	1.33	6.5	6.5	5.5	6.5	7.0	5.5
Mg	0.22	0.83	3.9E-2	0.18	0.55	0.25	5.6E-2	1.3	1.3	1.3	1.3	1.4	1.3
K	1.67	0.34	7.0E-2	8.10*	3.2E-2	0.21	3.0E-2	0.79	0.87	0.88	0.98	1.0	1.3
Na	10.9**	4.44*	1.1E-3	42.8**	0.21	3.01	4.27*	0.26	0.22	0.21	0.29	0.31	0.36
Mn	2.89	10.0**	0.27	9.15**	0.46	1.31	1.79	0.042	0.036	0.040	0.043	0.046	0.048

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error.

APPENDIX 9. 1981 AND 1982 KELP SOIL AMENDMENT ANALYSIS OF VARIANCE CALCULATED MEAN SQUARE TERMS, MEANS AND F-VALUES FOR FIELD SOIL STRUCTURE EFFECTS.

Measured structure variables	Source F-values			[a]MSE	[b]MS (T*B)	Curvilinear F-values			Mean values (Kelp Application t ha^{-1})			
	Treatment (T)	Block (B)	T*B			Linear	Quadratic	Deviant	0	30	60	120
1981												
Bulk density (kg m^{-3})	1.97	4.47**	2.29**	1320	3029	1.52	4.27	0.11	1010	980	955	980
Aeration porosity (m^3 m^{-3})	4.22*	5.14**	2.20*	5.6E-4	1.2E-3	1.36	7.34*	3.97	0.145	0.156	0.197	0.160
Total porosity (m^3 m^{-3})	1.47	2.63	2.17	2.3E-4	5.1E-4	1.70	0.78	1.92	0.591	0.590	0.606	0.600
Particle density (kg m^{-3})	1.85	0.77	0.51	1.4E-4	7.2E-4	4.8E-2	2.89	2.62	2470	2390	2430	2440
1982												
Bulk density (kg m^{-3})	9.7E-2	0.65	0.56	2043	1152	2.2E-2	0.25	1.4E-2	918	914	911	916
Aeration porosity (m^3 m^{-3})	0.52	3.05*	0.69	7.5E-4	5.2E-2	0.22	0.43	0.90	0.212	0.211	0.222	0.215
Total porosity (m^3 m^{-3})	0.45	0.89	0.41	2.1E-4	8.9E-5	1.6E-2	2.4E-3	1.36	0.631	0.627	0.632	0.629
Particle density (kg m^{-3})	0.54	4.08*	0.74	4917	3668	0.13	0.53	0.96	2490	2450	2470	2470

*,** Significant at 5% and 1% level, respectively.
[a] Mean square error for block and T*B F-ratio denominators.
[b] Mean Square (B*T) for treatment F-ratio denominator.

APPENDIX 10. KELP SOIL AMENDMENT GREENHOUSE EXPERIMENT I: KELP APPLICATION * SOIL INCUBATION PERIOD. ANALYSIS OF VARIANCE, CALCULATED [a]MSE AND F-VALUES FOR PLANT GROWTH AND SOIL CHEMICAL EFFECTS.

Measured variables	Source F-values				Curvilinear F-values											
					Rate			Incubation		Rate Incubation						
	Rate (R)	Incubation (Inc)	R*Inc	[a]MSE	Linear (R/L)	Quadratic (R/Q)	Deviant (R/D)	Linear (Inc/L)	Deviant (Inc/D)	Inc/L *R/L	Inc/L *R/Q	Inc/L *R/D	Inc/D *R/L	Inc/D *R/Q	Inc/D *R/D
Plant Growth Responses															
Emergence (% two-leaf stage)															
Day 12	10.3**	1.63	0.80	0.64	28.1**	2.02	0.94	0.51	2.75	2.5E-2	0.10	0.23	7.7E-2	0.68	3.80
Day 14	4.21**	0.69	1.38	0.37	10.6**	1.95	3.1E-2	0.49	0.90	2.48	5.5E-2	0.27	3.53	0.90	1.06
Day 16	3.40*	1.01	1.01	0.26	7.92**	2.21	7.3E-2	0.31	1.70	0.57	0.31	6.3E-2	3.06	1.70	0.34
Day 18	0.37	1.32	0.78	0.13	0.41	0.65	5.4E-2	1.37	1.27	1.50	0.15	3.0E-2	2.29	0.45	0.25
Yields (% of control)															
Fresh shoot	16.9**	1.17	2.52*	203	49.2**	0.78	0.72	5.7E-2	2.28	1.92	6.39*	4.13*	0.66	0.82	1.22
Fresh bean pod	17.8**	0.28	1.48	347	52.1**	1.37	8.1E-2	0.26	0.30	1.73	3.93	2.44	8.2E-2	0.16	0.57
Dry shoot	42.5**	1.44	2.40*	164	125**	0.10	2.34	0.32	2.56	1.73	4.17*	4.57*	0.11	2.49	1.32
Dry bean pod	26.8**	0.14	0.89	331	79.2**	1.02	0.38	0.20	8.3E-2	0.92	2.84	0.69	2.3E-3	0.24	0.64
Fresh/Dry Wt Ratios															
Bean pod	41.7**	1.05	0.34	1.03	124**	0.19	0.91	5.8E-3	2.05	1.4E-2	1.0E-2	7.0E-3	0.54	1.46	7.4E-2
Shoot	21.2**	1.87	0.45	2.87	62.4**	0.93	0.28	0.58	3.16	0.14	0.21	1.87	0.23	0.17	9.4E-2
Soil Chemical Effects															
NO_3-N (mg kg^{-1})	69.8**	1.20	0.60	203	139**	----	0.34	5.5E-3	2.40	0.29	----	9.5E-3	0.30	----	1.79
NH_4-N (mg kg^{-1})	30.3**	2.44	1.86	11.0	53.9**	----	6.73*	4.17*	0.70	6.75*	----	0.65	2.8E-2	----	2.9E-3
Soluble Cl (mg kg^{-1})	125**	7.39**	1.82	6.61	377**	9.1E-3	0.48	5.01*	9.77**	0.30	5.3E-3	2.8E-2	6.94*	3.25	0.39
pH(2:1 water:soil))	.74	2.20	2.22	6.5E-2	0.69	2.24	2.27	2.4E-2	4.38*	7.24**	2.56	0.75	0.52	2.0E-2	2.23
EC (dS m^{-1})	54.7**	0.61	0.10	0.22	161**	0.26	2.73	0.81	0.40	0.21	0.21	0.19	9.3E-4	1.1E-4	3.6E-3

*,** Significant at 5% and 1%, respectively.
[a] Mean square error.

APPENDIX 11. KELP SOIL AMENDMENT GREENHOUSE EXPERIMENT I: KELP APPLICATION * SOIL INCUBATION PERIOD. CURVILINEAR SIGNIFICANT EFFECTS AND CALCULATED MEAN VALUES FOR PLANT GROWTH AND SOIL CHEMICAL EFFECTS.

Measured variables	Soil Incubation Period (Weeks)												Curvilinear significant effects from Appendix 10
	1				3				5				
	Kelp Application (t ha^{-1})				Kelp Application (t ha^{-1})				Kelp Application (t ha^{-1})				
	0	15	60	120	0	15	60	120	0	15	60	120	
Plant Growth Responses													
Emergence (% two-leaf stage)													
Day 12	61	61	61	17	50	66	28	22	66	72	61	22	R/L
Day 14	100	87	87	55	87	94	87	87	87	94	94	72	R/L
Day 16	100	94	94	72	94	94	94	94	87	94	94	72	R/L
Day 18	100	100	94	87	94	94	100	100	87	94	94	87	
Yields (% of control)													
Fresh shoot	100	103	103	61.5	100	102	85.1	84.4	100	100	78.9	68.7	R/L; Inc/L*RQ; Inc/L*RD
Fresh bean pod	100	98.8	97.4	47.0	100	99.7	79.6	59.5	100	99.0	81.4	73.8	R/L
Dry shoot	100	101	92.1	49.0	100	104	78.2	68.8	100	97.6	69.5	59.0	R/L; Inc/L*RQ; Inc/L*RD
Dry bean pod	100	100	87.9	38.0	100	100	73.5	50.9	100	96.5	77.2	59.1	R/L
Fresh/Dry Wt Ratios													
Bean pod	5.88	5.88	6.53	7.40	6.11	6.15	6.83	7.28	5.88	5.88	6.52	7.38	R/L
Shoot	4.87	4.67	5.22	5.90	4.95	4.95	5.37	5.98	4.78	4.82	4.97	5.88	R/L
Soil Chemical Effects													
NO_3-N (mg kg^{-1})	22	a	43	77	26	a	57	78	18	a	43	80	R/L
NH_4-N (mg kg^{-1})	2.6	a	5.0	14	2.3	a	3.8	10	3.2	a	4.0	8.0	R/L; R/D; Inc/L; Inc/L*R/L
Soluble Cl (mg kg^{-1})	200	350	700	1100	290	450	830	1500	270	470	820	1300	R/L; Inc/D; Inc/D*R/L
pH (2:1 water:soil)	5.3	5.2	5.0	5.0	5.1	4.8	5.1	5.1	5.2	5.0	5.1	5.4	Inc/D; Inc/L*R/L
EC (dS m^{-1})	0.55	1.0	1.4	2.6	0.70	1.1	1.6	2.6	0.72	1.1	1.6	2.5	R/L

[a] Not sampled.

APPENDIX 12. KELP SOIL AMENDMENT GREENHOUSE EXPERIMENT II: KELP APPLICATION * SOIL LEACHING. ANALYSIS OF VARIANCE CALCULATED [a]MSE AND F-VALUES FOR PLANT GROWTH AND SOIL CHEMICAL EFFECTS.

Measured variables	Soluble F-values			[a]MSE	Curvilinear F-values			
					Rate		Rate * Leaching	
	Rate (R)	Leaching (Lch)	R*LCH		Linear (R/L)	Deviant (R/D)	R/L*Lch	R/D*Lch
Plant Growth Responses								
Emergence (% two-leaf stage)								
Day 9	5.29**	44.0**	4.66*	1.77	2.25	8.33**	9.00**	0.33
Day 10	2.89	33.2**	6.01**	2.00	5.00*	0.78	11.65**	0.37
Day 11	0.32	8.47**	2.65	1.59	0.62	2.3E-2	3.41	1.80
Day 12	0.30	0.62	3.11	0.73	0.15	0.45	3.77	2.46
Yields (% of control)								
Fresh shoot	14.0**	0.44	4.05*	7.32	22.8**	5.17*	7.35**	0.75
Dry shoot	1.04	10.7**	5.32**	0.20	1.84	0.23	10.2**	0.44
Fresh/Dry Wt Ratios								
Shoot	76.4**	30.3**	2.54	2.15	142**	10.5**	0.51	4.56
Soil Chemical Effects								
NO_3-N (mg kg^{-1})	61.8**	97.1**	59.0**	47.3	107**	16.5**	99.9**	18.0**
NH_4-N (mg kg^{-1})	8.00**	5.71*	5.25**	1.78	12.3**	3.66	5.72*	4.78*
Soluble Cl (mg kg^{-1})	144**	281**	60.5**	1.3E-4	288**	2.6E-3	120**	0.11
pH (2:1 water:soil)	44.5**	89.9**	2.19	4.1E-2	54.1**	34.9**	4.10**	0.27
EC (dS m^{-1})	196**	353**	79.5**	3.9E-2	391**	1.05	158**	0.76

*,** Significant at 5% and 1% level, respectively.
[a] Mean Square error.

APPENDIX 13. KELP SOIL AMENDMENT GREENHOUSE EXPERIMENT II: KELP APPLICATION * SOIL LEACHING. CURVILINEAR SIGNIFICANT EFFECTS AND CALCULATED MEAN VALUES FOR PLANT GROWTH AND SOIL CHEMICAL EFFECTS.

Measured variables	Soil not leached			Soil leached			Curvilinear Significant effects from Appendix 12.
	Kelp application(t ha^{-1})			Kelp application (t ha^{-1})			
	0	60	120	0	60	120	
Plant Growth Responses							
Emergence (% two-leaf stage)							
Day 9	21	2.2	1.1	23	33	40	R/D; R/L*Lch
Day 10	59	44	32	63	67	72	R/L; R/L*Lch
Day 11	64	63	53	67	70	74	
Day 12	72	71	65	68	71	75	
Yields (% of control)							
Fresh shoot	100	123	113	100	134	151	R/L; R/D; R/L*Lch
Dry shoot	100	87.8	77.1	100	110	110	R/L * Lch
Fresh/dry wt ratios							
Shoot	5.18	7.00	7.24	4.71	5.65	6.62	R/L; R/D; R/D*Lch
Soil Chemical Effects							
NO_3-N (mg kg^{-1})	5.8	13	52	4.6	5.4	5.5	R/L; R/D; R/L*Lch; R/D*Lch
NH_4-N (mg kg^{-1})	4.1	1.1	1.4	1.6	1.4	1.1	R/L; R/L*Lch; R/D*Lch
Soluble Cl (mg kg^{-1})	150	680	1200	40	170	270	R/L; R/L*Lch
pH (2:1 water:soil)	5.4	4.4	4.7	5.7	5.2	5.4	R/L; R/D; R/L*Lch
EC (dS m^{-1})	0.44	1.4	2.6	0.23	0.46	0.71	R/L; R/L*Lch

APPENDIX 14. 1983 KELP FOLIAR SPRAY ANALYSIS OF VARIANCE CALCULATED MEAN SQUARES, F-VALUES AND TREATMENT MEAN VALUES FOR BEAN GROWTH RESPONSES

Measured growth variables	Source F-values: Treatment (T)	Source F-values: Block (B)	[a]MSE	[b]Treatment mean separation F-values: C vs E1+E2+M1+M2+K	K vs E1+E2+M1+M2	E1+E2 vs M1+M2	E1+M1 vs E2+M2	E1+M2 vs E2+M1	[b]Treatment mean values: C	M1	M2	E1	E2	K
Yields (t ha^{-1}):														
Dry shoot	1.66	2.29	0.33	4.67*	0.78	0.46	0.48	1.91	3.87	4.61	4.81	4.81	4.21	4.33
Dry bean pod	2.59	6.77**	2.0E-2	7.85*	0.10	4.68*	7.7E-3	0.57	1.04	1.35	1.32	1.16	1.21	1.23
Dry leaf & stem wt	1.40	1.41	0.27	2.64	0.82	2.6E-2	0.64	2.87	2.83	3.26	3.49	3.64	3.00	3.09
Fresh shoot wt	1.68	0.44	8.58	6.01*	0.19	1.84	0.22	0.16	33.4	38.5	38.4	37.1	35.9	36.8
Fresh bean pod	2.30	4.07*	3.44	7.57*	1.4E-2	1.66	0.38	1.88	13.8	17.6	16.9	15.1	17.0	16.5
Harvest index (%)	1.02	2.14	1.2E-3	0.19	0.33	0.88	0.37	3.31	26.9	29.4	27.3	24.5	28.8	28.6
Fresh/dry wt ratio	1.57	4.47*	0.26	1.41	1.04	2.3E-3	1.03	4.35	8.62	8.37	8.10	7.82	8.62	8.52

*,**Significant at 5% and 1% level, respectively.
[a]Mean square error.
[b]See text for description of abbreviations.

APPENDIX 15. 1983 KELP FOLIAR SPRAY ANALYSIS OF VARIANCE AND COVARIANCE CALCULATED MEAN SQUARES, F-VALUES AND MEAN OR ADJUSTED MEAN VALUES FOR BEAN LEAF & STEM AND POD ELEMENTAL CONCENTRATION.

Measured concentration variables	Soil covariate	Source F-values: Treatment (T)	Source F-values: Block (B)	[a]MSE	[b]Treatment mean separation F-values: CvsE1+E2+M1+M2+K	KvsE1+E2+M1+M2	E1+E2 vs M1+M2	E1+M1 vs E2+M2	E1+M2 vs E2+M1	F-values for covariance test of regression equation	[b]Treatment mean or adjusted mean values: C	M1	M2	E1	E2	K
Leaf & stem;																
N %	--	1.20	13.1**	3.8E-2	1.7E-3	1.61	3.1E-2	2.88	1.47		1.88	2.00	1.70	1.88	1.84	1.99
	pH	2.06	12.2**	3.0E-2						4.93*	1.82	2.00	1.67	1.90	1.85	2.04
P %	--	0.76	5.78**	2.1E-4	0.16	1.95	2.8E-2	1.0E-2	1.66		0.17	0.18	0.17	0.17	0.18	0.19
K %	--	0.49	3.19	4.6E-2	0.40	0.27	0.21	1.35	0.21		1.8	2.0	1.8	1.9	1.8	2.0
Ca %	--	0.88	15.3	9.8E-2	1.90	1.26	9.2-11	1.01	0.25		1.2	1.3	1.2	1.3	1.3	1.3
Mg %	--	0.66	1.62	5.2E-4	0.87	2.21	1.9E-2	0.10	0.96		0.21	0.22	0.21	0.21	0.22	0.23
Fe mg kg^{-1}	--	1.32	1.23	2358	3.18	0.21	0.16	1.28	1.79		210	150	150	130	190	170
	pH	2.12	1.62	1235						14.6**	190	160	140	140	200	190
Cu mg kg^{-1}	--	0.43	3.04	0.91	0.32	0.21	0.27	0.27	1.09		6.7	7.0	6.7	6.7	7.5	7.2
Mn mg kg^{-1}	--	0.78	1.35	315	0.61	1.53	8.7E-2	0.94	0.73		99	100	110	100	110	120
	Mn	1.28	0.56	243						5.44*	90	100	110	100	110	120
Zn mg kg^{-1}	--	1.43	8.80**	2.83	2.6E-2	1.27	0.55	2.67	2.67		24	25	23	23	23	23
Bean Pod;																
N %	--	0.55	5.91**	2.3E-2	0.46	1.9E-3	0.24	1.97	8.6E-2		2.04	2.01	1.93	2.07	1.94	1.99
P %	--	1.16	8.25**	1.6E-4	1.4E-2	0.25	2.46	1.12	1.99		0.29	0.28	0.29	0.30	0.29	0.29
K %	--	4.38*	2.47	3.4E-2	9.39**	0.17	1.8E-2	0.88	11.4**		2.2	2.0	1.7	1.6	2.0	1.9
Ca %	--	1.63	2.90	1.1E-3	1.95	3.28	0.20	2.3E-2	2.72		0.47	0.46	0.44	0.44	0.48	0.42
Mg %	--	2.63	1.19	1.8E-4	7.29*	6.4E-2	7.5#-2	3.3E-4	5.75*		0.21	0.20	0.18	0.19	0.20	0.19
Fe mg kg^{-1}	--	0.69	1.52	196	1.08	1.24	0.12	0.50	0.50		80	72	72	80	70	65
Cu mg kg^{-1}	--	0.60	7.60**	0.27	0.48	0.72	0.40	0.90	0		7.0	7.5	7.2	7.2	7.0	7.0
	pH	1.02	4.3*	0.21						5.76*	6.8	7.5	7.2	7.3	7.0	7.1
Mn mg kg^{-1}	--	1.12	11.7**	10.6	0.80	0.38	9.3E-2	2.82	1.50		43	39	44	42	42	41
	Mn	1.68	3.73*	7.61						6.97*	41	39	45	43	42	41
Zn mg kg^{-1}	--	0.68	1.66	7.62	0.15	0.86	8.1E-2	2.36	8.1E-3		20	20	18	20	18	18

*,**Significant at 5% and 1% level, respectively.
[a]MSE; Mean square error.
[b]See text for description of abbreviations.

APPENDIX 16. 1983 KELP FOLIAR SPRAY ANALYSIS OF VARIANCE AND COVARIANCE CALCULATED MEAN SQUARES, F-VALUES AND MEAN OR ADJUSTED MEAN VALUES FOR BEAN LEAF & STEM AMD POD ELEMENTAL UPTAKE.

Measured uptake variables	Soil covariate	Source F-values: Treatment (T)	Source F-values: Block (B)	[a]MSE	[b]Treatment mean separation F-values: CvsE1+E2+M1+M2+K	KvsE1+E2+M1+M2	E1+E2 vs M1+M2	E1+M1 vs E2+M2	E1+M2 vs E2+M1	F-values for covariance test of regression equation	[b]Treatment mean or adjusted mean values: C	M1	M2	E1	E2	K
Leaf & stem;																
N kg ha^{-1}	--	0.80	2.13	151	1.11	3.9E-3	1.8E-3	2.54	0.36		54.4	64.4	58.3	68.4	54.8	61.9
	pH	2.16	3.72*	95						9.86**	49.6	65.3	56.3	69.3	55.7	65.7
P kg ha^{-1}	--	0.66	0.65	1.09	1.96	5.7E-3	4.6E-4	0.73	0.62		5.0	5.9	5.8	6.2	5.4	5.8
	pH	2.10	2.62	0.65						11.1**	4.6	5.9	5.6	6.3	5.5	6.1
K kg ha^{-1}	--	1.15	0.61	154	2.23	9.3E-2	7.9E-2	2.20	1.17		53	66	63	71	55	62
	pH	1.94	1.49	123						4.79*	49	67	62	72	55	65
Ca kg ha^{-1}	--	1.07	1.35	58.0	2.97	2.6E-2	9.6E-3	1.47	0.90		35	43	42	46	38	43
	pH	2.66	1.37	37.5						9.19**	32	44	41	47	39	45
Mg kg ha^{-1}	--	0.62	0.22	1.77	1.64	1.8E-2	3.3E-2	0.86	0.55		6.2	7.2	7.1	7.6	6.5	7.2
	pH	1.77	1.83	1.15						9.00**	5.7	7.3	6.9	7.7	6.6	7.6
Fe g ha^{-1}	--	0.26	0.85	4.1E4	0.78	1.0E-5	2.9E-2	0.34	0.17		620	500	520	480	580	520
	pH	0.55	3.82*	1.7E4						21.5**	520	520	480	500	600	600
Cu g ha^{-1}	--	0.39	0.75	29.7	1.45	0.12	5.2E-2	0.17	0.17		19	23	23	25	22	22
	pH	1.22	1.75	20.2						8.02*	17	23	22	25	23	24
Mn g ha^{-1}	--	0.82	2.41	4583	3.65	7.6E-2	0.21	1.1E-2	0.14		280	350	360	340	340	360
Zn g ha^{-1}	--	1.11	0.96	211	1.53	1.27	0.13	1.84	0.77		68	82	79	86	70	70
	pH	1.97	2.43	151						6.93*	63	83	77	87	71	74
Bean pod;																
N kg ha^{-1}	--	3.15*	1.71	5.51	9.11**	1.0E-2	4.80*	1.63	0.21		20.8	27.1	25.0	23.9	23.0	24.6
P kg ha^{-1}	--	1.55	1.71	0.20	6.06*	0.10	1.40	0.14	4.6E-2		3.0	3.8	3.7	3.5	3.5	3.5
K kg ha^{-1}	--	2.60	1.50	9.06	0.33	0.16	3.04-2	6.2E-2	9.43**		22	26	22	19	24	24
Ca kg ha^{-1}	--	1.67	2.26	0.60	3.11	1.47	1.66	5.9E-3	2.10		4.9	6.3	5.8	5.2	5.8	5.2
Mg kg ha^{-1}	--	1.82	5.66**	8.7E-2	1.88	0.18	2.70	1.4E-2	4.34		2.2	2.7	2.4	2.2	2.5	2.4
Fe g ha^{-1}	--	0.58	1.75	387	0.52	0.99	0.79	0.40	0.20		82	97	95	93	82	81
Cu g ha^{-1}	--	3.81*	3.90*	1.37	10.1*	1.10	5.50*	1.13	1.13		7.0	10	9.2	8.5	8.5	8.5
Mn g ha^{-1}	--	1.53	13.5**	52.0	4.35	0.48	1.82	1.00	1.1E-3		44	54	57	49	53	50
Zn g ha^{-1}	--	1.59	0.78	14.2	2.93	0.59	1.74	2.51	0.15		20	27	23	24	22	22

*,**Significant at 5% and 1% level, respectively.
[a]Mean square error.
[b]See text for description of abbreviations.

APPENDIX 17. 1984 KELP FOLIAR SPRAY ANALYSIS OF VARIANCE CALCULATED MEAN SQUARES, F-VALUES AND TREATMENT MEAN VALUES FOR BEAN GROWTH RESPONSES.

Measured growth variables	Source F-values			[a]MSE	[b]MS (T*B)	[c]Treatment mean separation F-values					[c]Treatment mean values					
	Treatment (T)	Block (B)	T*B			CvsS1+ S2+M1 +M2+K	KvsS1 +S2+ M1+M2	S1+S2 vs M1+M2	S1+M1 vs S2+M2	S1+M2 vs S2+M1	C	M1	M2	S1	S2	K
Yield (t ha^{-1});																
Dry shoot	2.41	1.97	0.92	0.23	0.21	2.68	4.81	0.14	3.82	0.49	5.53	5.89	6.12	5.67	6.19	5.50
Dry bean pod	3.39	4.06	0.87	3.2E-2	2.8E-2	7.39*	6.04	2.33	1.04	0.22	1.05	1.29	1.39	1.22	1.26	1.10
Dry leaf & stem	1.07	0.62	1.41	0.15	0.22	0.40	1.63	2.3E-2	2.45	0.85	4.48	4.60	4.72	4.45	4.93	4.40
Fresh shoot	3.59	4.25	0.58	18.6	10.8	9.69*	4.24	0.30	3.12	0.61	41.6	46.6	47.9	44.7	48.2	43.7
Fresh bean pod	4.34	5.12*	0.52	4.72	2.48	12.7*	3.19	3.30	1.77	0.72	13.4	16.0	17.4	15.4	15.7	14.8
Fresh/dry wt ratio	0.66	2.42	1.20	0.17	0.20	2.91	0.17	1.3E-2	0.23	7.9E-3	7.52	7.90	7.83	7.90	7.79	7.94
Harvest index (%)	1.26	2.49	1.62	5.78	9.42	3.10	1.31	1.27	7.0E-4	0.63	18.9	21.8	22.8	21.4	20.4	20.0

*,**Significant at 5% and 1%, respectively.
[a]MSE; mean square error, used as denominator for calculation of source B and T*B F-values.
[b]MS(T*B); mean square treatment * block, used as denominator of source T F-values.
[c]See text for description of abbreviations.

APPENDIX 18. 1984 KELP FOLIAR SPRAY ANALYSIS OF VARIANCE AND COVARIANCE CALCULATED MEAN SQUARES, F-VALUES AND TREATMENT MEAN OR ADJUSTED MEAN FOR BEAN LEAF AND STEM AND POD ELEMENTAL CONCENTRATION.

Measured growth variables	Soil covariate	Source F-values: Treatment (T)	Block (B)	T*B	[a]MSE	[b]MS (T*B)	[c]Treatment mean separation F-values: CvsS1+S2+M1+M2+K	KvsS1+S2+M1+M2	S1+S2 vs M1+M2	S1+M1 vs S2+M2	S1+M2 vs S2+M1	F-value for covariance test of regression equation	[c]Treatment mean or adjusted mean values: C	M1	M2	S1	S2	K
Leaf & stem;																		
N%	--	3.82	3.87	0.64	5.4E-2	3.5E-2	1.95	0.82	11.1*	1.15	4.04		2.99	2.76	2.69	2.86	3.10	2.93
P%	--	6.31*	8.8E-2	1.21	3.0E-4	3.6E-4	1.8E-3	1.21	20.0**	2.01	8.26*		0.29	0.29	0.26	0.30	0.31	0.31
	%C	5.29*	0.66	1.33	2.6E-4	3.5E-4						4.32*	0.29	0.29	0.26	K0.30	0.31	0.30
K%	--	4.15	4.08	0.39	5.4E-2	2.1E-2	6.06	13.2*	0.50	1.9E-4	0.98		2.7	2.5	2.5	2.5	2.6	2.8
Ca%	--	0.18	3.17	0.52	0.13	6.9E-2	0.28	5.6E-2	2.9E-3	0.20	0.35		1.7	1.7	1.8	1.8	1.8	1.7
	pH	1.03	0.21	1.55	4.9E-2	7.6E-2						4.22**	1.7	1.6	1.9	1.9	1.9	1.9
Mg%	--	7.65*	6.65*	0.14	2.6E-2	3.7E-4	17.1*	1.33	13.6*	0.97	5.14		0.40	0.42	0.43	0.47	0.44	0.43
	Mg	4.78	9.49*	0.52	1.5E-3	8.2E-4						16.4**	0.43	0.41	0.39	0.46	0.45	0.46
Fe mg kg^{-1}	--	0.85	3.02	0.39	8614	3422	0.49	2.4E-2	1.75	1.94	7.7E-2		180	170	190	190	230	190
	pH	2.09	0.70	0.52	6605	3439						8.39**	190	140	160	200	250	210
	Fe	1.68	2.99	0.71	6637	4727						8.24**	180	150	160	200	260	210
Cu mg kg^{-1}	--	3.29	0.84	0.71	0.52	0.37	0.23	2.2E-2	13.3*	0.11	2.75		11	11	11	12	12	11
Mn mg kg^{-1}	--	4.40	19.6**	0.60	115	69.2	6.29	2.25	14.4*	29.E-2	6.0E-4		68	52	51	65	64	64
	pH	1.18	15.5**	1.06	66.2	70.8						18.6**	66	55	57	63	62	61
	%C	2.26	16.9**	1.01	96.1	97.6						5.72*	68	53	53	64	64	62
Zn mg kg^{-1}	--	1.34	8.2E-3	1.40	13.5	18.9	1.69	2.22	2.11	0.17	0.49		41	36	37	40	38	41
	pH	0.60	1.19	1.83	10.4	19.2						8.02**	41	37	38	39	37	40
Bean pods;																		
N%	--	1.90	0.67	0.30	5.9E-2	1.8E-2	4.72	1.78	1.43	1.16	0.42		3.39	3.20	3.22	3.23	3.32	3.32
	pH	1.10	2.47	0.33	5.1E-2	1.7E-2						4.54*	3.37	3.24	3.29	3.20	3.29	3.29
	%C	1.23	1.91	0.41	5.1E-2	2.1E-2						4.65*	3.39	3.22	3.26	3.21	3.31	3.29
P%	--	8.76*	0.85	0.13	8.7E-4	1.1E-4	2.68	12.7*	17.0**	3.1E-3	11.4*		0.48	0.47	0.46	0.48	0.49	0.49
	pH	15.0**	7.7E-3	0.15	7.2E-4	1.1E-4						5.98*	0.49	0.47	0.45	0.48	0.50	0.50
K%	--	1.74	5.06*	0.46	1.2E-2	5.8E-3	3.47	3.70	0.28	1.2E-2	1.24		2.5	2.4	2.5	2.5	2.5	2.5
	K	3.34	8.24*	0.51	1.0E-2	5.3E-3						6.27*	2.6	2.4	2.4	2.5	2.5	2.5
Ca%	--	1.58	0.17	0.37	2.3E-3	8.7E-4	9.1E-2	5.65	1.72	0.23	0.23		0.56	0.58	0.58	0.57	0.56	0.54
	pH	0.39	1.04	1.13	1.4E-3	5.8E-4						19.0**	0.57	0.57	0.56	0.58	0.57	0.55
	Ca	0.46	0.26	0.41	6.6E-4	3.0E-4						11.6**	0.57	0.57	0.55	0.57	0.57	0.56
Mg%	--	0.33	4.76*	2.02	1.2E-4	2.5E-4	2.6E-2	0.39	0.34	0.89	3.1E-2		0.28	0.28	0.27	0.28	0.28	0.27
Fe mg kg^{-1}	--	1.88	0.44	0.37	100	37.7	1.47	2.20	3.97	0	1.76		47	55	52	47	50	47
	pH	0.82	0.38	0.56	61.1	34.5						16.2**	48	52	47	48	52	49
	Fe	1.18	0.27	0.41	83.6	34.3						5.69*	47	53	48	47	52	48
Cu mg kg^{-1}	--	2.47	1.96	0.52	0.69	0.36	1.5E-2	2.79	9.34*	0.11	0.11		11	11	10	12	11	11
	%C	1.08	4.83*	0.77	0.54	0.42						7.46*	11	11	11	11	11	11
	Cu	0.52	6.81*	0.98	0.57	0.57						5.91*	11	11	11	11	11	11
Mn mg kg^{-1}	--	2.01	18.2**	0.58	24.9	14.5	3.38	0.20	6.34	7.1E-2	7.1E-2		36	31	30	35	35	33
	pH	0.41	17.9**	1.49	9.53	14.2						38.8**	35	33	33	33	33	32
	%C	1.03	15.5**	0.94	20.9	19.7						5.59*	36	32	31	34	34	33
	Mn	0.36	32.4**	1.33	17.3	23.0						11.5**	35	33	32	33	34	33
Zn mg kg^{-1}	--	4.14	2.51	0.53	3.19	1.69	9.91*	0.49	0.39	9.8E-2	9.83*		32	31	29	29	31	31

*,**Significant at 5% and 1%, respectively.
[a]MSE; mean square error, used as denominator for calculation of source B and T*B F-values.
[b]MS(T*B); mean square treatment * block, used as denominator of source T F-values.
[c]See text for description of abbreviations.

APPENDIX 19. 1984 KELP FOLIAR SPRAY ANALYSIS OF VARIANCE AND COVARIANCE CALCULATED MEAN SQUARES, F-VALUES AND TREATMENT MEAN OR ADJUSTED MEAN VALUES FOR BEAN LEAF AND STEM AND POD ELEMENTAL UPTAKE.

Measured uptake variables	Soil covariate	Source F-values: Treatment (T)	Block (B)	B*T	[a]MSE	[b]MS (T*B)	[c]Treatment mean separation F-values: CvsS1+S2+M1+M2+K	KvsS1+S2+M1+M2	S1+S2 vs M1+M2	S1+M1 vs S2+M2	S1+M2 vs S2+M1	F-value for covariance test of regression equation	[c]Treatment mean or adjusted mean values: C	M1	M2	S1	S2	K
Leaf & stem;																		
N kg ha^{-1}	--	2.68	4.27*	1.28	1.83	2.35-2	1.8E-2	0.36	4.30	4.41	4.30		133	127	127	127	153	130
P kg ha^{-1}	--	1.88	0.77	1.95	1.95	3.83	0.18	0.15	4.52	0.21	4.34		13	13	12	13	15	13
K kg ha^{-1}	--	1.52	1.45	0.62	165	103	0.48	0.58	0.25	3.63	2.64		120	120	120	110	130	120
Ca kg ha^{-1}	--	0.71	3.25	0.54	417	225	0.82	0.84	4.2E-2	1.83	4.3E-2		76	79	86	79	89	77
	pH	1.53	0.28	1.25	171	215						35.3**	80	72	75	84	94	83
	Ca	0.57	5.71*	1.75	240	422						18.6**	81	75	73	80	91	88
Mg kg ha^{-1}	--	2.14*	7.24*	0.66	7.94	5.25	4.37	2.38	2.74	1.18	3.1E-2		18	19	20	21	22	19
	Mg	1.22	8.59**	1.41	5.99	8.51						8.78**	19	19	18	20	22	20
Fe g ha^{-1}	--	1.11	2.63	0.47	2.6E5	1.2E5	0.65	0.18	1.49	2.74	0.50		790	780	910	850	1200	860
	pH	2.16	0.48	0.62	2.0E5	1.2E5						8.91**	850	650	710	930	1300	960
	Fe	1.70	2.49	0.78	2.1E5	1.6E5						7.06*	800	670	730	900	1300	960
Cu g ha^{-1}	--	1.80	1.08	0.69	38.3	26.6	0.99	1.27	4.58	2.13	1.2E-2		50	49	52	53	57	50
Mn g ha^{-1}	--	1.93	13.5**	1.04	3051	3176	1.85	7.9E-2	6.99*	0.53	0.20		310	240	240	290	310	280
	pH	1.74	8.54**	1.40	2279	3194						9.12**	300	250	270	280	300	270
	%C	1.15	10.9**	1.54	2671	4125						4.40*	310	240	250	280	310	270
Zn g ha^{-1}	--	0.92	0.11	0.73	419	309	0.69	0.10	2.63	1.18	8.6E-3		180	170	170	180	190	180
	Zn	1.20	1.30	1.05	361	382						4.80**	190	160	170	180	190	180
Bean pod;																		
N kg ha^{-1}	--	1.62	6.12*	1.25	33.5	42.1	2.96	2.84	0.88	1.42	1.5E-2		35.7	41.2	44.7	39.0	41.8	36.7
P kg ha^{-1}	--	1.83	5.54*	0.96	0.88	0.84	5.17	2.66	0.61	0.69	2.2E-2		5.1	6.2	6.4	5.8	6.2	5.5
K kg ha^{-1}	--	3.36	6.60*	0.65	22.4	14.6	7.12*	4.82	2.91	1.37	0.55		27	32	35	30	31	28
Ca kg ha^{-1}	--	6.08*	3.46	0.44	1.64	0.73	10.7*	12.8*	5.31	0.94	0.61		5.9	7.5	8.2	7.0	7.1	6.0
	pH	2.59	1.06	0.68	1.33	0.91						6.47**	6.0	7.3	7.7	7.2	7.3	6.3
Mg kg ha^{-1}	--	3.90*	6.14*	0.65	0.29	0.19	8.71*	8.25*	1.86	0.42	0.28		2.9	3.6	3.8	3.5	3.5	3.0
Fe g ha^{-1}	--	6.07*	3.25	0.40	103	627	12.0*	9.49*	7.79	0.49	0.55		47	72	72	57	63	52
	pH	2.75	0.56	0.63	159	101						15.3**	50	57	64	60	67	55
Cu g ha^{-1}	--	2.59	6.87*	0.70	4.29	3.02	7.65*	4.20	0.13	0.69	0.30		12	14	15	14	14	13
Mn g ha^{-1}	--	0.77	3.66	0.98	62.6	61.5	0.74	2.50-2	0.32*	0.27	2.7E-3		38	40	42	42	43	36
	pH	1.26	1.20	1.08	51.5	55.9						6.18**	37	42	44	41	42	35
Zn g kg^{-1}	--	1.68	7.36*	1.37	29.8	41.1	3.45	3.42	1.95	0.40	0.19-3		33	41	41	36	39	34

*,**Significant at 5% and 1%, respectively.
[a]MSE; mean square error, used as denominator for calculation of source B and T*B F-values.
[b]MS(T*B); mean square treatment * block, used as denominator of source T F-values.
[c]See text for description of abbreviations.

APPENDIX 20. 1983 AND 1984 KELP FOLIAR SPRAY FIELD TRIALS SOIL ANALYSIS OF BLOCK AND PLOT COMPOSITES AT SEEDING AND HARVEST.

Measured soil variable	1983 Field Trial		1984 Field Trial	
	Mean of block composite samples at seeding n = 4	Grand mean of plot composite samples at harvest n = 24	Mean of block composite samples at seeding n = 2	Grand mean of plot composite samples at harvest n = 36
pH (2:1 water:soil)	4.6	4.6	5.6	5.6
C %	2.7	2.6	1.9	1.8
N %	0.28	0.29	0.21	0.20
Available P mg kg^{-1}	60	59	50	50
Available cations (mg kg^{-1});				
K	280	220	220	150
Ca	970	920	1500	1300
Mg	140	130	260	200
Fe	170	170	160	160
Cu	10	10	9.5	9.7
Mn	54	46	54	48
Zn	5.0	4.4	5.5	5.3

APPENDIX 21. KELP FOLIAR SPRAY GREENHOUSE EXPERIMENT: SOIL MOISTURE * KELP FOLIAR SPRAY ANALYSIS OF VARIANCE CALCULATED [a]MSE AND F-VALUES FOR PLANT GROWTH RESPONSES.

	Source F- values						Mean Separation F-Values							
							[b]Soil Moisture		[b]Foliar Spray		[b]Soil Moisture * Foliar Spray			
Measured uptake variables	Block (B)	Soil Moisture (θ)	Foliar spray (S)	θ*S	θ*S*B	[a]MSE	FC vs D+W	D vs W	C vs K + S	K vs S	C vs K + S * FC vs D + W	C vs K + S * D vs W	K vs S * FC vs D + W	K vs S * D vs W
Harvest I; Day 37:														
Yields (g pot^{-1})														
Fresh wt shoot	0.15	26.2**	4.27*	0.93	2.45*	103	1.18	51.1**	8.51**	3.7E-2	1.72	0.42	1.28	0.31
Dry wt leaf	2.34	18.0**	5.99**	4.42**	2.41*	0.69	1.5E-2	36.0**	11.1**	0.84	6.86*	4.56*	4.52*	1.75
Dry wt stem	7.4E-3	11.9**	7.83**	1.66	2.42*	0.22	0.62	23.3**	14.1**	1.50	1.34	3.12	1.84	0.32
Dry wt root	7.5E-3	3.47*	6.45**	1.96	0.69	0.31	1.95	4.99*	12.7**	0.11	0.24	2.38	4.36*	0.86
Dry wt shoot	1.18	18.0**	7.72**	3.76*	2.77*	1.47	5.0E-2	36.1**	14.2**	1.23	5.10*	4.68*	3.96	1.28
Dry wt plant	1.16	18.3**	12.1**	5.18**	2.56*	1.95	0.69	36.0**	23.6**	0.68	5.09*	7.14*	6.63*	1.85
Leaf Area (cm^2 pot $^{-1}$)	4.3E-3	13.4**	1.11	0.44	2.37*	1.5E-7	1.56	25.3**	2.16	7.7E-2	0.53	0.53	0.69	6.2E-3
LAR (cm^2 g^{-1})	1.11	3.90*	3.46*	1.28	0.65	452	6.29*	1.51	5.96*	0.97	1.28	1.97	0.86	0.99
SLA (cm^2 g^{-1})	3.18	1.56	1.99	1.67	0.49	1499	2.97	0.15	2.75	1.23	3.18	1.30	0.80	1.41
Nodule rating	1.8E-2	10.6**	0.40	0.87	0.36	0.35	1.0E-3	21.3**	0.69	0.11	1.00	2.24	0.22	1.8E-2
Height (cm)	0.71	12.1**	1.38	0.65	1.33	32.6	0.76	24.1**	1.57	1.19	8.5E-2	6.6E-2	1.93	0.53
# Nodes	7.90*	7.3E-2	0.29	0.14	0.49	0.18	0.10	3.6E-2	0.43	0.14	1.2E-11	7.3E-2	0.29	0.21
Fresh/dry wt ratio	5.63*	6.57**	3.00*	1.72	0.39	0.25	7.09*	6.05*	2.22	3.78	2.92	3.79	0.77	0.21
Shoot/root ratio	5.0E-2	2.00	2.30	0.31	0.67	0.71	2.07	1.93	3.65	0.94	2.6E-2	0.67	0.40	0.16
Harvest II, Day 62:														
Yields (g pot^{-1})														
Fresh wt shoot	0.37	7.86**	4.42*	3.05*	1.76	1351	13.7**	1.98	2.61	6.23*	1.85	3.83	0.67	6.34*
Dry wt leaf & stem	6.3E-2	6.16**	3.67*	1.54	1.16	6.97	11.6**	0.72	1.16	6.18*	0.45	2.08	2.3E-4	3.64
Dry wt leaf	0.25	5.74**	3.00	1.32	0.72	2.59	9.63**	1.85	1.02	4.98*	0.68	1.28	0.57	2.74
Dry wt stem	1.2E-2	4.58*	2.94	1.64	1.36	1.74	9.17**	1.9E-3	0.85	5.03*	0.11	2.28	0.91	3.25
Dry wt root	0.34	1.22	3.96*	2.43	1.09	1.44	0.33	2.10	2.21	5.70*	4.69*	1.37	0.15	3.50
Dry wt shoot	0.28	5.88**	3.92*	2.43	1.71	48.3	10.9**	0.83	1.80	6.03*	1.06	2.25	0.31	6.08*
Dry wt beans	0.82	4.66*	3.34*	2.57	2.03	22.7	8.59**	0.73	1.85	4.84*	1.27	1.92	0.68	6.40*
Dry wt plant	0.33	4.54*	3.98*	2.14	1.60	57.0	8.71**	0.37	1.00	6.96*	0.36	1.43	0.20	6.58*
Leaf Area (cm^2 pot^{-1})	0.12	4.44*	2.57	2.71*	1.84	3.3E-5	8.41**	0.48	0.26	4.88*	5.0E-2	5.64*	0.13	5.03*
LAR (cm^2 g^{-1})	2.2E-5	0.36	0.42	2.45	0.92	32.8	0.41	0.31	0.85	3.3E-5	0.47	9.12**	0.12	7.1E-2
SLA (cm^2 g^{-1})	1.01	0.39	0.17	1.56	2.01	1552	6.9E-2	0.73	0.31	2.1E-2	0.16	4.24*	0.44	1.38
Nodule Rating	0.13	0.58	1.52	2.08	1.39	0.35	1.13	2.8E-2	0.93	2.11	4.2E-2	1.13	3.9E-2	7.12*
Height (cm)	1.2E-2	9.46**	0.50	0.81	0.77	44.7	0.44	18.4**	0.11	0.89	4.5E-2	3.04	0.12	5.9E-2
# Nodes	2.61	0.49	3.49*	0.96	0.58	0.31	0.29	0.68	6.20*	0.78	0.73	2.19	9.8E-2	0.81
Fresh/dry wt ratio	2.2E-2	0.44	0.43	0.42	0.72	8.0E-2	0.19	0.69	8.6E-2	0.78	5.2E-2	0.50	0.47	0.67
Shoot/root ratio	0.51	10.2**	1.79	4.52**	1.36	2.31	12.0**	8.45**	3.42	0.15	12.9**	4.62*	0.20	0.28
# beans > 6 cm	2.07	8.68**	2.87	3.40*	1.22	10.2	17.3**	2.6E-3	2.24	3.49	4.58*	3.78	2.73	2.52

*,**Significant at 5% and 1% level, respectively.
[a]MSE; Mean square error, used as denominator for calculation of source F-values.
[b]See text for description of abbreviations.

APPENDIX 22. KELP FOLIAR SPRAY GREENHOUSE EXPERIMENT: SOIL MOISTURE * KELP FOLIAR SPRAY TREATMENT MEAN VALUES FOR BEAN GROWTH AND DEVELOPMENT AND SIGNIFICANT CONTRASTS.

	Mean Growth or Development Values									Significant treatment contrasts (From Appendix 21)		
	[a]Soil Moisture											
	D			FC			W					
	[a]Foliar Sprays											Soil Moisture *
Measured growth variable	C	S	K	C	S	K	C	S	K	Soil Moisture	Foliar Spray	Foliar Spray
Harvest I; Day 37: Yields (g pot^{-1})												
Fresh wt shoot	73.6	82.7	82.4	86.4	92.6	86.5	94.7	106	110	D vs W	C vs K + S	------
Dry wt leaf	6.44	6.95	7.17	7.72	7.92	7.34	7.27	8.59	9.71	D vs W	C vs K + S	C vs K + S * FC vs D + W C vs K + S * D vs W K vs S * FC vs D + W
Dry wt stem	3.44	3.66	3.89	3.96	4.31	4.20	3.81	4.51	4.96	D vs W	C vs K + S	------
Dry wt root	2.51	2.84	2.84	2.85	3.63	3.01	2.52	3.25	3.68	D vs W	C vs K + S	K vs S * FC vs D + W
Dry wt shoot	9.89	10.6	11.1	11.7	12.2	11.5	11.1	13.1	14.7	D vs W	C vs K + S	C vs K + S * FC vs D + W C vs K + S * D vs W
Dry wt plant	12.4	13.4	13.9	14.5	15.9	14.5	13.4	16.3	18.4	D vs W	C vs K + S	C vs K + S * FC vs D + W C vs K + S * D vs W K vs S * FC vs D + W
Leaf area (cm^2 pot^{-1})	2540	2640	2690	2780	2930	2730	3070	3380	3410	D vs W	------	------
LAR (cm^2 g^{-1})	204	196	193	190	184	186	227	206	186	FC vs D + W	C vs K + S	------
SLA (cm^2 g^{-1})	395	380	376	361	369	371	421	393	352	------	------	------
Nodule rating	1.5	1.4	1.5	2.0	1.8	2.0	2.0	2.6	2.7	D vs W	------	------
Height (cm)	41	41	43	44	44	50	50	53	51	D vs W	------	------
Fresh/dry wt ratio	7.68	7.81	7.47	7.38	7.58	7.46	8.56	8.09	7.56	FC vs D + W D vs W	------	------
Shoot/root ratio	4.10	3.76	4.05	4.16	3.38	3.90	4.82	4.13	4.14	------	------	------
# Nodes	6.7	6.5	6.6	6.6	6.4	6.6	6.6	6.6	6.5	------	------	------
Harvest II; Day 62: Yields (g pot^{-1})												
Fresh wt shoot	195	253	238	262	236	281	209	182	243	FC vs D + W	K vs S	K vs S * D vs W
Dry wt leaf & stem	16.8	20.2	19.4	20.6	29.6	21.8	17.8	15.5	19.8	FC vs D + W	K vs S	------
Dry wt leaf	8.47	9.94	9.76	10.5	9.56	11.3	8.60	7.69	9.69	FC vs D + W	K vs S	------
Dry wt stem	8.30	9.29	9.60	10.1	10.1	10.5	9.22	7.83	10.1	FC vs D + W	K vs S	------
Dry wt roots	6.31	4.68	4.83	5.00	5.18	5.91	6.22	4.68	6.66	------	K vs S	C vs K + S * FC vs D + W
Dry wt shoot	33.2	42.2	40.0	44.2	40.2	47.7	36.0	30.6	42.3	FC vs D + W	K vs S	K vs S * D vs W
Dry wt beans	16.4	22.9	20.6	23.4	20.7	25.9	18.2	15.1	22.6	FC vs D + W	K vs S	K vs S * D vs W
Dry wt plant	39.5	46.9	44.0	49.2	45.4	53.6	42.2	35.3	49.0	FC vs D + W	K vs S	K vs S * D vs W
Leaf area (cm^2 pot^{-1})	2650	3330	3180	3550	3220	3740	3160	2340	3250	FC vs D + W	K vs S	C vs K vs S * D vs W K vs S * D vs W
LAR (cm^2 g^{-1})	67.2	71.1	70.9	70.2	70.8	69.8	74.3	65.3	66.4	------	------	C vs K + S * D vs W
SLA (cm^2 g^{-1})	312	339	324	327	334	320	362	311	335	------	------	C vs K + S * D vs W
Nodule rating	2.0	2.2	1.9	2.3	2.1	2.3	2.4	1.5	2.4	------	------	K vs S * D vs W
Height (cm)	47	49	51	54	52	53	62	55	59	D vs W	------	------
Fresh/dry wt ratio	5.92	6.00	5.97	5.93	5.87	5.88	5.94	5.97	5.75	------	------	------
Shoot/root ratio	5.64	9.07	8.38	9.43	7.94	8.07	5.70	6.49	6.46	FC vs D + W D vsW	------	C vs K + S * FC vs D + W C vs K + S * D vs W
# beans > 6 cm	18.8	24.5	23.2	27.0	23.3	27.8	21.8	21.0	23.3	FC vs D + W	------	C vs K + S * FC vs D + W
# nodes	8.5	8.1	8.5	8.7	8.4	8.5	9.0	8.2	8.2	------	C vs K + S	------

[a] See text for description of abbreviations.

APPENDIX 23: KELP FOLIAR SPRAY GREENHOUSE EXPERIMENT: SOIL MOISTURE * KELP FOLIAR SPRAY ANALYSIS OF VARIANCE CALCULATED [a]MSE AND F-VALUES FOR LEAF & STEM AND BEAN POD ELEMENTAL CONCENTRATION

	Source F-values						Mean Separation F-Values							
							[b]Soil Moisture		[b]Foliar Spray		[b]Soil Moisture * Foliar Spray			
Measured uptake variables	Block (B)	Soil Moisture (θ)	Foliar spray (S)	θ*S	θ*S*B	[a]MSE	FC vs D+W	D vs W	C vs S K + S	K vs S	C vs K + S * FC vs D + W	C vs K + S * D vs W	K vs S * FC vs D + W	K vs S * D vs W
Harvest I; Day 37														
Leaf + stem;														
N%	5.68*	15.3**	0.15	1.93	1.77	6.9E-2	1.75	28.8**	0.28	3.1E-2	5.00**	4.0E-2	0.12	2.55
P%	0.89	1.38	0.51	2.04	0.34	1.6E-3	2.60	0.17	0.37	0.65	0.37	4.14*	3.34	0.32
K%	2.29	2.98	2.26	2.73*	0.45	5.8E-2	0.83	5.13*	3.32	1.20	8.34**	1.04	3.96	1.59
Ca%	0.33	1.90	3.20	1.12	0.41	2.0E-2	1.83	1.98	2.42	3.97	0.58	0.24	0.68	2.97
Mg%	0.19	4.30*	2.52	2.51	0.31	1.4E-3	2.53	6.07*	0.64	4.40*	4.59*	0.75	1.95	2.76
Fe mg kg^{-1}	7.6E-4	2.12	1.77	0.26	0.45	2431	0.27	3.97	1.23	2.31	6.8E-3	2.2E-3	0.51	0.55
Cu mg kg^{-1}	3.7E-2	8.62**	4.62*	0.80	0.47	2.00	3.89	13.3**	4.74*	4.50*	1.44	0.17	0.56	1.02
Mn mg kg^{-1}	6.4E-3	2.23	1.28	1.17	0.79	1146	2.46	1.99	0.61	1.94	0.93	1.2E-3	2.30	1.45
Zn mg kg^{-1}	1.41	45.2**	0.62	1.30	0.44	19.9	8.21**	82.3**	0.98	0.27	0.12	0.40	2.59	2.00
Harvest II - Day 62:														
Leaf + stem;														
N%	2.85	3.0E-2	0.97	1.82	0.71	0.22	9.7E-3	5.1E-2	5.1E-2	1.90	0.75	1.21	0.36	4.97*
P%	2.80	2.30	1.05	0.60	1.16	4.9E-4	4.61*	6.8E-3	1.56	0.54	2.14	0.22	1.0E-2	5.2E-2
K%	0.36	11.4**	6.59**	0.52	0.58	4.1E-2	6.78*	16.1**	1.88	11.3**	7.1E-2	5.3E-2	1.3E-2	1.97
Ca%	6.05*	0.43	4.05*	2.18	1.99	5.9E-2	0.39	0.46	0.97	7.12*	2.90	0.67	2.1E-2	5.12*
Mg%	0.10	1.17	1.12	1.60	0.88	2.2E-3	1.1E-2	2.33	2.00	0.24	4.40*	2.5E-2	1.99	1.6E-2
Fe mg kg^{-1}	4.73*	7.56**	0.50	1.83	0.47	625	4.47*	10.6**	0.37	0.63	3.32	0.10	0.97	2.93
Cu mg kg^{-1}	6.08*	9.75**	74.1**	1.64	0.85	0.68	9.13**	10.3**	62.4**	85.7**	3.57	2.45	0.50	6.0E-2
Mn mg kg^{-1}	4.76*	15.5**	3.36*	0.70	0.83	621	4.10	26.9**	1.15	5.56*	1.58	2.8E-2	5.7E-3	1.20
Zn mg kg^{-1}	5.7E-2	16.0**	0.36	1.77	1.25	8.00	19.2**	12.9**	0.66	5.5E-2	3.25	3.21	0.50	0.13
Bean pod;														
N%	2.59	9.7E-3	2.95	2.12	1.21	0.10	1.5E-2	4.5E-2	8.9E-6	5.90*	6.8E-2	1.03	1.5E-2	7.37*
P%	1.02	4.35*	1.10	2.18	1.61	3.9E-4	2.70	6.00*	0.52	1.69	3.0E-2	4.28*	2.05	2.37
K%	0.24	2.00	8.94**	1.68	1.84	6.2E-2	2.03	1.96	3.28	11.6**	9.0E-2	0.98	2.0E-2	5.63*
Ca%	1.63	1.69	7.16**	1.76	2.37*	9.7E-3	2.76	0.62	3.71	8.60**	7.2E-2	0.49	3.1E-2	6.44*
Mg%	0.38	2.52	3.53*	3.44*	0.83	2.3E-3	2.51	2.52	0.73	6.32*	3.3E-4	2.64	0.27	10.8**
Fe mg kg^{-1}	5.40*	12.2**	40.9**	3.25*	2.48*	137	2.43	22.0**	31.2**	50.6**	4.62*	2.28	3.65	2.46
Cu mg kg^{-1}	5.1E-2	9.90**	14.2**	1.33	1.27	1.42	3.43	16.3**	14.3**	14.2**	5.1E-2	0.97	1.40	2.92
Mn mg kg^{-1}	6.2E-2	8.25**	2.24	1.03	0.67	18.8	1.76	14.7**	3.71	0.77	8.8E-3	3.40	0.14	0.56
Zn mg kg^{-1}	0.19	13.5**	1.29	2.82*	2.79*	9.68	9.56**	17.4**	2.11	0.48	0.25	6.82*	7.0E-2	4.13*

*,**Significant at 5% and 1% level, respectively.

[a]Mean square error.

[b]See text for description of abbreviations.

APPENDIX 24. KELP FOLIAR SPRAY GREENHOUSE EXPERIMENT: SOIL MOISTURE * KELP FOLIAR SPRAY CALCULATED MEAN VALUES AND SIGNIFICANT CONTRASTS FOR LEAF AND BEAN POD ELEMENTAL CONCENTRATIONS

	Mean Concentration Values									Significant treatment contrasts (From Appendix 23)		
	[a]Soil Moisture											
	D			FC			W					
	[a]Foliar Sprays											
Measured concentration variable	C	S	K	C	S	K	C	S	K	Soil Moisture	Foliar Spray	Soil Moisture * Foliar Spray
Harvest I; Day 37:												
Leaf & stem												
N%	2.99	2.78	2.91	2.42	2.60	2.63	2.54	2.46	2.25	D vs W	------	C vs K + S * FC vs D + W
P%	0.39	0.42	0.40	0.38	0.37	0.40	0.43	0.41	0.37	------	------	C vs K + S * D vs W
K%	3.3	3.1	3.2	2.9	2.9	3.3	3.3	3.0	2.8	D vs W	------	C vs K + S * FC vs D + W
Ca%	1.3	1.40	1.4	1.3	1.3	1.4	1.4	1.4	1.4	------	------	------
Mg%	0.42	0.42	0.41	0.39	0.41	0.46	0.46	0.42	0.46	D vs W	K vs S	C vs K + S * FC vs D + W
Fe mg kg^{-1}	140	170	140	160	200	160	170	190	190	------	------	------
Cu mg kg^{-1}	6.5	7.2	7.3	6.0	6.8	8.3	8.5	8.3	9.5	D vs W	C vs K + S K vs S	------
Mn mg kg^{-1}	140	160	110	160	130	140	120	130	110	------	------	------
Zn mg kg^{-1}	32	36	32	35	35	39	47	46	48	FC vs D + W D vs W	------	------
Harvest II; Day 62:												
Leaf & stem												
N%	1.70	2.14	1.86	1.91	1.67	2.02	1.98	1.54	2.13	------	------	K vs S * D vs W
P%	0.20	0.21	0.21	0.20	0.19	0.20	0.20	0.21	0.22	FC vs D + W	------	------
K%	1.3	1.3	1.2	1.3	1.2	1.1	1.6	1.7	1.3	FC vs D + W D vs W	K vs S	------
Ca%	1.5	1.7	1.7	1.7	1.5	1.7	1.6	1.5	1.9	------	K vs S	K vs S * D vs W
Mg%	0.30	0.29	0.30	0.35	0.31	0.27	0.32	0.32	0.33	------	------	C vs K + S * FC vs D + W
Fe mg kg^{-1}	140	170	150	160	160	140	170	180	190	FC vs D + W D vs W	-----	------
Cu mg kg^{-1}	2.0	3.5	5.8	2.7	2.5	5.3	3.5	4.0	6.5	FC vs D + W D vs W	C vs K + S K vs S	------
Mn mg kg^{-1}	110	120	130	120	100	120	69	66	96	D vs W	K vs S	------
Zn mg kg^{-1}	21	20	20	20	17	18	22	25	24	FC vs D + W D vs W	------	------
Bean pods												
N%	2.05	2.22	2.14	2.17	2.02	2.26	2.21	1.80	2.42	------	K vs S	K vs S * D vs W
P%	0.29	0.26	0.27	0.27	0.28	0.26	0.28	0.30	0.29	D vs W	------	C vs K + S * D vs W
K%	1.9	1.7	1.6	1.8	1.8	1.5	1.9	2.1	1.6	------	K vs S	K vs S * D vs W
Ca%	0.44	0.34	0.35	0.38	0.37	0.27	0.43	0.48	0.29	------	K vs S	K vs S * D vs W
Mg%	0.27	0.22	0.24	0.24	0.24	0.21	0.26	0.33	0.22	------	K vs S	K vs S * D vs W
Fe mg kg^{-1}	87	82	52	97	87	48	97	97	83	D vs W	C vs K + S K vs S	C vs K + S * FC vs D + W
Cu mg kg^{-1}	1.7	2.0	4.7	2.0	3.0	3.8	3.8	4.2	5.2	D vs W	C vs K + S K vs S	------
Mn mg kg^{-1}	35	28	31	32	29	29	25	26	26	D vs W	------	------
Zn mg kg^{-1}	21	16	17	17	18	17	22	25	21	FC vs D + W D vs W	------	C vs K + S * D vs W K vs S * D vs W

[a]See text for description of abbreviations.

APPENDIX 25. KELP FOLIAR SPRAY GREENHOUSE EXPERIMENT: SOIL MOISTURE * KELP FOLIAR SPRAY ANALYSIS OF VARIANCE CALCULATED [a]MSE AND F-VALUES FOR LEAF & STEM AND BEAN POD ELEMENTAL UPTAKE - HARVEST I AND II.

	Source F- values						Mean Separation F-Values							
							[b]Soil Moisture		[b]Foliar Spray		[b]Soil Moisture and Foliar Spray			
Measured uptake variables	Block (B)	Soil Moisture (θ)	Foliar spray (S)	θ*S	θ*S*B	[a]MSE	FC vs D+W	D vs W	C vs K + S	K vs S	C vs K + S * FC vs D + W	C vs K + S * D vs W	K vs S * FC vs D + W	K vs S * D vs W
Harvest I; Day 37:														
Leaf & stem (mg pot^{-1}):														
N	0.30	0.64	2.85	1.35	2.37*	1608	7.7E-2	1.20	5.19*	0.51	6.3E-3	1.91	1.99	1.48
P	9.2E-2	9.22**	1.48	0.24	1.31	62.5	0.38	18.0**	2.80	0.15	0.74	0.17	1.7E-2	4.3E-2
K	3.2E-2	6.02**	2.65	0.45	1.76	2475	7.3E-4	12.0**	2.83	2.46	2.9E-5	1.34	0.14	0.32
Ca	1.05	13.2**	7.22**	1.32	1.42	777	0.22	26.1**	8.58**	5.86*	0.42	2.25	0.55	2.08
Mg	0.38	18.2**	7.14**	1.12	1.20	58.0	0.48	35.9**	8.69**	5.58*	0.12	1.69	0.61	2.07
Fe	0.10	7.67**	2.40	0.95	0.64	0.42	0.18	15.1**	4.07	0.73	0.34	0.88	1.90	0.70
Cu	0.39	19.7**	11.6**	1.18	1.08	3.7E-4	2.35	37.0**	15.2**	8.00**	1.2E-3	1.94	0.29	2.48
Mn	0.20	2.08	0.31	1.05	1.42	0.19	2.88	1.28	0.12	0.51	2.14	0.70	0.45	0.91
Zn	2.05	53.2**	5.08	1.45	1.15	6.2E-3	4.21*	102**	8.38**	1.77	1.36	2.10	0.16	2.18
Harvest II; Day 62:														
Leaf & stem (mg pot^{-1})														
N	0.98	0.88	1.88	1.94	0.82	1.4E-4	1.65	0.12	0.26	3.49	0.75	1.72	0.30	5.00*
P	0.53	0.73	3.26*	1.01	1.40	55.4	1.22	0.24	1.94	4.57*	1.50	0.51	5.5E-3	2.03
K	1.38	6.67**	0.55	0.88	1.06	842	0.95	12.3**	7.9E-2	1.03	0.48	1.56	0.68	0.81
Ca	1.23	1.04	4.92*	2.46	1.49	5605	2.03	6.4E-2	1.37	8.47**	2.20	1.91	3.0E-2	5.69*
Mg	2.6E-2	3.27*	1.03	2.54	0.99	126	6.17*	0.36	0.24	1.82	5.88*	0.65	1.52	2.13
Fe	2.68	1.64	0.86	2.76	0.88	0.45	0.26	3.01	0.67	1.04	2.63	0.66	0.94	2.42
Cu	3.49	3.12	73.1*	1.50	1.24	3.3E-4	1.00	5.23*	53.9*	92.3*	1.34	2.21	0.33	2.12
Mn	2.33	14.4**	4.93*	1.21	0.84	0.32	9.62**	19.2**	2.00	7.87**	1.69	0.75	6.4E-2	2.34
Zn	0.17	2.23	3.17	1.94	0.46	4.2E-3	0.46	4.01	2.1E-2	4.33	3.42	4.7E-2	3.2E-2	2.67
Bean pod (mg pot^{-1}):														
N	1.29	1.73	2.94	2.28	1.37	2.3E-4	3.35	0.12	0.71	5.16*	0.65	1.43	0.38	6.67*
P	2.50	4.77*	3.67*	2.58	2.32*	124	9.48*	6.5E-2	2.01	5.32*	2.05	0.79	5.7E-	7.44**
K	1.70	7.97**	0.37	3.26	2.46*	2.8E-3	15.3**	0.57	3.7E-3	0.73	4.94*	1.77	0.17	6.14*
Ca	0.17	7.45**	1.68	3.79*	0.96	84.8	12.0**	2.89	2.23	1.13	11.6**	1.94	4.7E-2	1.48
Mg	0.65	1.70	0.52	0.94	1.86	150	3.35	5.7E-2	0.94	9.3E-2	2.50	1.6E-3	1.26	4.4E-5
Fe	6.67*	2.60	4.40*	5.64**	1.31	0.17	2.96	2.24	4.11*	4.70*	8.66**	0.30	1.08	12.5**
Cu	7.4E-2	6.57**	47.2**	0.72	0.84	3.9E-4	0.18	12.9**	38.8**	55.5**	9.4E-2	1.85	0.42	0.51
Mn	1.98	18.2**	5.88**	2.39	1.51	1.3E-2	22.8**	13.6**	0.27	11.4**	3.57	0.13	0.80	8.06*
Zn	1.54	4.02*	6.41**	2.38	2.33*	4.1E-3	3.68	4.36*	0.72	12.1**	2.01	0.14	0.50	6.87*

*,**Significant at 5% and 1% level, respectively.
[a]MSE; Mean square error.
[b]See text for description of abbreviations.

APPENDIX 26. KELP FOLIAR SPRAY GREENHOUSE EXPERIMENT: SOIL MOISTURE * KELP FOLIAR SPRAY TREATMENT MEAN VALUES AND SIGNIFICANT CONTRASTS FOR LEAF & STEM AND BEAN POD ELEMENTAL UPTAKE.

	Mean Uptake Values									Significant treatment contrasts (From Appendix 25)		
	[a]Soil Moisture											
	D			FC			W					
	[a]Foliar Sprays											
Measured uptake variable	C	S	K	C	S	K	C	S	K	Soil Moisture	Foliar Spray	Soil Moisture * Foliar Spray
Harvest I; Day 37:												
Leaf & stem (mg pot^{-1})												
N	292	300	321	284	318	301	281	325	329	------	C vs K + S	------
P	39	42	44	45	46	46	48	54	55	D vs W	------	------
K	330	310	360	350	360	380	360	400	420	D vs W	------	------
Ca	130	140	150	150	160	170	160	180	230	D vs W	C vs K + S K vs S	------
Mg	41	43	46	46	49	53	51	56	68	D vs W	C vs K + S K vs S	------
Fe	1.4	1.8	1.6	1.9	2.5	1.8	2.0	2.5	2.8	D vs W	------	------
Cu	6.5E-2	7.3E-2	8.1E-2	7.0E-2	8.5E-2	9.8E-2	9.1E-2	0.11	0.14	D vs W	C vs K + S K vs S	------
Mn	1.4	1.6	1.2	1.8	1.6	1.6	1.4	1.7	1.7	------	------	------
Zn	0.31	0.36	0.36	0.41	0.43	0.45	0.53	0.61	0.70	FC vs D + W D vs W	C vs K + S	------
Harvest II; Day 62:												
Leaf & stem (mg pot^{-1})												
N	293	412	362	410	333	437	353	253	420	------	------	K vs S * D vs W
P	34	40	41	41	38	43	35	34	43	------	K vs S	------
K	220	240	230	260	260	240	270	260	270	D vs W	------	------
Ca	250	340	330	350	290	370	300	240	390	------	K vs S	K vs S * D vs W
Mg	50	56	58	72	60	59	56	50	65	FC vs D + W	------	C vs K + S * FC vs D + W
Fe	2.4	3.2	2.8	3.3	3.1	3.0	3.1	2.7	3.8	------	------	K vs S * D vs W
Cu	3.6E-2	6.6E-2	0.11	5.3E-2	5.2E-2	0.11	6.3E-2	6.8E-2	0.13	D vs W	C vs K + S K vs S	------
Mn	1.9	2.4	2.5	2.4	2.0	2.6	1.3	1.0	1.9	FC vs D + W D vs W	K vs S	------
Zn	0.35	0.37	0.38	0.42	0.33	0.39	0.38	0.38	0.37	------	------	------
Bean pods (mg pot^{-1})												
N	354	515	447	520	427	587	423	292	548	-----	K vs S	K vs S * D vs W
P	46	59	55	64	57	67	50	44	64	FC vs D + W	K vs S	K vs S * D vs W
K	300	380	330	420	360	390	320	290	360	FC vs D + W	------	C vs K + S * FC vs D + W K vs S * D vs W
Ca	66	77	69	88	73	70	67	64	65	FC vs D + W	------	C vs K + S * FC vs D + W
Mg	41	50	48	56	48	56	42	51	49	------	------	------
Fe	1.4	1.9	1.1	2.2	1.7	1.2	1.7	1.4	1.8	------	C vs K + S K vs S	C vs K + S * FC vs D + W K vs S * D vs W
Cu	3.1E-2	4.5E-2	9.1E-2	4.5E-2	5.6E-2	0.10	5.8E-2	5.6E-2	0.11	D vs W	C vs K + S K vs S	------
Mn	0.55	0.63	0.63	0.74	0.58	0.76	0.43	0.37	0.58	FC vs D + W D vs W	K vs S	K vs S * D vs W
Zn	0.33	0.35	0.35	0.42	0.35	0.44	0.36	0.34	0.47	D vs W	K vs S	K vs S * D vs W

[a]See text for description of abbreviations.