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Effects of kelp (*Macrocystis integrifolia*) on soil chemical properties and crop response

W.D. TEMPLE and A.A. BOMKE
Department of Soil Science, University of British Columbia, Vancouver, B.C., Canada

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Abstract

In 1981 a two-year field plot experiment was established to assess the effects of quantities (0, 7.5, 15, 30, 60 and 120 t ha^{-1}) of fresh kelp (*Macrocystis integrifolia*) on crop growth and nutritional response and chemical properties of a fine-textured soil. Soil was analyzed for NO_3-N, NH_4-N, electrical conductivity, pH, Cl and exchangeable cations (K, Mg, Ca, Mn and Na). The plots were planted to beans (*Phaseolus vulgaris*) in the first year and peas (*Pisum sativum*) in the second year. Marketable bean yields increased in the first year with kelp applications up to 60 t ha^{-1}, with yields, emergence and flowering being reduced by the 120 t ha^{-1} application. Soluble salts (EC) and Cl concentrations in the soil eight days after application increased linearly and sharply with increasing quantities of kelp. Increased K concentration and moisture content, characteristics of plants growing in a salt-stressed soil environment, were measured. A subsequent companion greenhouse experiment confirmed that the reduced bean emergence and growth with 120 t ha^{-1} applications of kelp were primarily due to soluble salts. The only growth effects upon peas in the second year was a slight reduction in leaf plus stem yields with increasing applications of kelp.

Introduction

In Europe large brown alga (Phaeophyta) or kelp have been used as a soil amendment since the twelfth century and is still commonly used on the coastal lands of France, Ireland and Britain (Chapman, 1970). Application of this amendment is along the coast of Brittany and the nearby Channel Islands. The success of kelp in the genesis of soil is particularly evident in the Channel Islands, where the land in crop production has been increased by applying a mixture of kelp and sand to areas previously lacking agriculturally productive soils (Stephenson, 1968). The word kelp itself was used by fertilizer companies during the early 1900's to refer to the burnt ash or potash of the brown kelps.

Quantitative investigations into the use of fresh kelp as a soil amendment have been few. The objective of this investigation was to determine the effects of increasing rates of fresh kelp applied to a fine textured soil on crop growth and nutritional responses and soil chemical properties.

Materials and methods

1981 and 1982 field trials

On 19 June 1981 mature kelp (*Macrocystis integrifolia*) was harvested just offshore and south of Port Hardy, British Columbia. The kelp was cut one meter beneath the surface of the water with a mechanical harvester and chopped into pieces of less than 4 cm as it was conveyed into a barge. The kelp was then placed in plastic-lined totes, covered and transported to the study site on Westham Island, B.C., part of the Fraser River delta.

The soil of the study site is classified as Westham SiCL (45% clay, 45% 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 20 cm, left to air dry and passed through a 2 mm sieve. The Westham 0–20 cm 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 P_1- extractable P of 70 mg kg^{-1}, exchangeable K, Mg, Na, Ca and Mn concentrations of 0.81, 1.5, 0.21, 7.2 and 0.046 c mol^+ 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 analyses are described below.

On 24 June, kelp (with 11 % dry matter) 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 × 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 0–20 cm soil layer just beneath the overlying 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 15 cm. Seven days after disking (Day 1) bush beans (*Phaseolus vulgaris*) were inoculated (*Rhizobium phaseoli*) and planted at a depth of 3.5 m 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*) field peas (*Pisum sativum*) planted on 6 May (Day 1) to a depth of 3.5 cm. The plots received no additional mineral fertilizer or kelp during the second year. Composite soil and bulk density samples (0–20 cm) were taken from each plot five days prior to seeding of peas in the second year.

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 mapped at approximately the same time of day. From the mapped sequence of emerging plants, ten plants were randomly selected for emergence counts. At harvest, one kg leaf plus stem and marketable 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 1.2 m × 2.0 m the first year and 2.0 m × 2.0 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 sub-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 (0–20 cm) were taken from each of the plots on the harvest dates.

Greenhouse experiments

Kelp (*M. Integrifolia*) was harvested on July 20, 1981, offshore from Sooke, British Columbia. The kelp was placed in self-sealing plastic bags and transported in an icebox back to the laboratory in Vancouver. Twelve hours after harvest the kelp was cut into less than 4 cm pieces, 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 0–20 cm zone of the plough layer beside the field plot area. 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, 1975). Subsamples 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. Pots were amended at rates 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}.

Experiment I. The four kelp applications were applied in factorial combination with the previously mixed kelp plus soil subsequently incubated for

periods of 1, 3 or 5 weeks prior to 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 5 cm to give 40 g of soil for pH, Cl and electrical conductivity (EC) determinations. Bush bean (*P. vulgaris*) seeds were wetted and inoculated (*R. phaseoli*) just prior to sowing three seeds per pot at a depth of 4 cm (Day 1). Incubation periods were timed so that all pots were sown at the same time. The seed, fertilizer, inoculant, kelp and soil used in this experiment were the same as those used in the field plot investigation.

Emergence was assessed each day by counting the number of plants at the two-leaf stage in each of the pots. Once the plants had reached the two-leaf stage they were thinned to two plants per pot. At harvest (Day 74) 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 60 °C in a forced air oven to a constant weight and weighed immediately for dry weight and moisture content.

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 and NO_3-N analyses 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. Three of the six replicates of each combination of incubation period and kelp application (excluding the 15 t ha^{-1} application) from Experiment I were randomly assigned to the leached and 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 replicates selected for 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 two groups were not significantly different except 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 pots received a volume of tap water equal to twice its total porosity of 0.62 $m^3 m^{-3}$ (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 equilibrate for one week. The soils were then sampled as described for Experiment I and analysed for pH, EC and Cl. The following day (Day 1) eight bean seeds were sown to a depth of 4 cm 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.

Laboratory procedures

Plant material. Grab samples of fresh kelp were taken from each of the six totes on the day of field application and placed in self sealing plastic bags. The bags were placed in an ice box, transported back to the laboratory, weighed and stored in the freezer at −15 °C. The kelp was thawed and then dried at 60 °C in a forced air oven to a constant weight for elemental analysis and moisture content determination. Crop samples were brought in from the field in paper bags and dried at 70 °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 concentration determined with the Perkin-Elmer 330 atomic absorption spectrophotometer. Cu and Pb were determined on kelp only. N and P were determined colourimetrically using a Technicon Autoanalyzer II (Technicon, 1974 a). Carbon was determined with a Leco Analyzer (Leco Manual, 1959) and kelp S with a Fisher S Analyzer Model 475 (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 10.0 g of plant material in 50.0 mL of distilled water for 30 min. and filtering (Whatman #42). All elemental concentrations are expressed on a dry weight basis.

Soil samples. The exchangeable cations K, Mg, Ca, Mn and Na were extracted with 1 *M* NH_4OAc adjusted to pH 5.0 (Chapman, 1965 a) with a subsequent CEC determination (Chapman 1965 b). 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, 1974 b). 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 concentrations 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 it 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).

Table 1. Elemental concentrations of the kelp, *Macrocystis integrifolia*, used in the field trial (Port Hardy Kelp) and greenhouse experiments (Sooke Kelp)

Element	Elemental concentration of dry kelp[a]	
	Port Hardy kelp n = 6	Sooke kelp n = 1
C%	27.3[b](7.00)	27.2
N%	2.34(5.47)	2.40
P%	0.39(2.8)	0.41
K%	8.7(4.1)	8.4
Ca%	1.21(8.59)	1.12
Mg%	0.76(3.5)	0.71
Na%	2.78(5.18)	2.74
S%	1.0(20)	0.90
Cl%	17.8(1.16)	18.0
Fe mg kg^{-1}	430(34)	360
Al mg kg^{-1}	220(38)	330
B mg kg^{-1}	177(2.45)	174
Zn mg kg^{-1}	12(42)	10
Mn mg kg^{-1}	7(30)	9
Cu mg kg^{-1}	< 1	< 1
Pb mg kg^{-1}	< 1	< 1

[a] Wet kelp contained 11% dry matter.
[b] Numbers in parentheses are the calculated coefficients of variation.

Available P was determined colourimetrically following extraction with 0.03M NH_4F in 0.025M HCl (Olsen and Dean, 1965). All quantitative measurements were based on air dry weight. Rainfall data was obtained from Environmental Canada, Delta Ladner South Weather Station.

Statistical analysis

Field data was subjected to analyses 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. Greenhouse data was 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). Application by incubation interactions 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, INC/D*R/L application effects were partitioned to 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.

Results

Field trials

Plant yield and composition. The elemental composition of the kelp is presented in Table 1. During the first growing season the 120 t ha^{-1} application of fresh kelp significantly reduced emergence (Figure 1). The leaves of bean plants in plots which had received 120 t ha^{-1} of fresh kelp were darker green in comparison to plots with lower application rates. During the first growing season, dry leaf plus stem, marketable (> 8 cm) bean pods and total shoot yields were reduced with the 120 t ha^{-1} application. The bean leaf plus stem and total shoot fresh/dry weight ratio also increased with increasing kelp application. In the subsequent growing season the residual effects of increasing kelp application had no effect on pea emergence and fresh/dry weight ratios. The only growth variable to be significantly

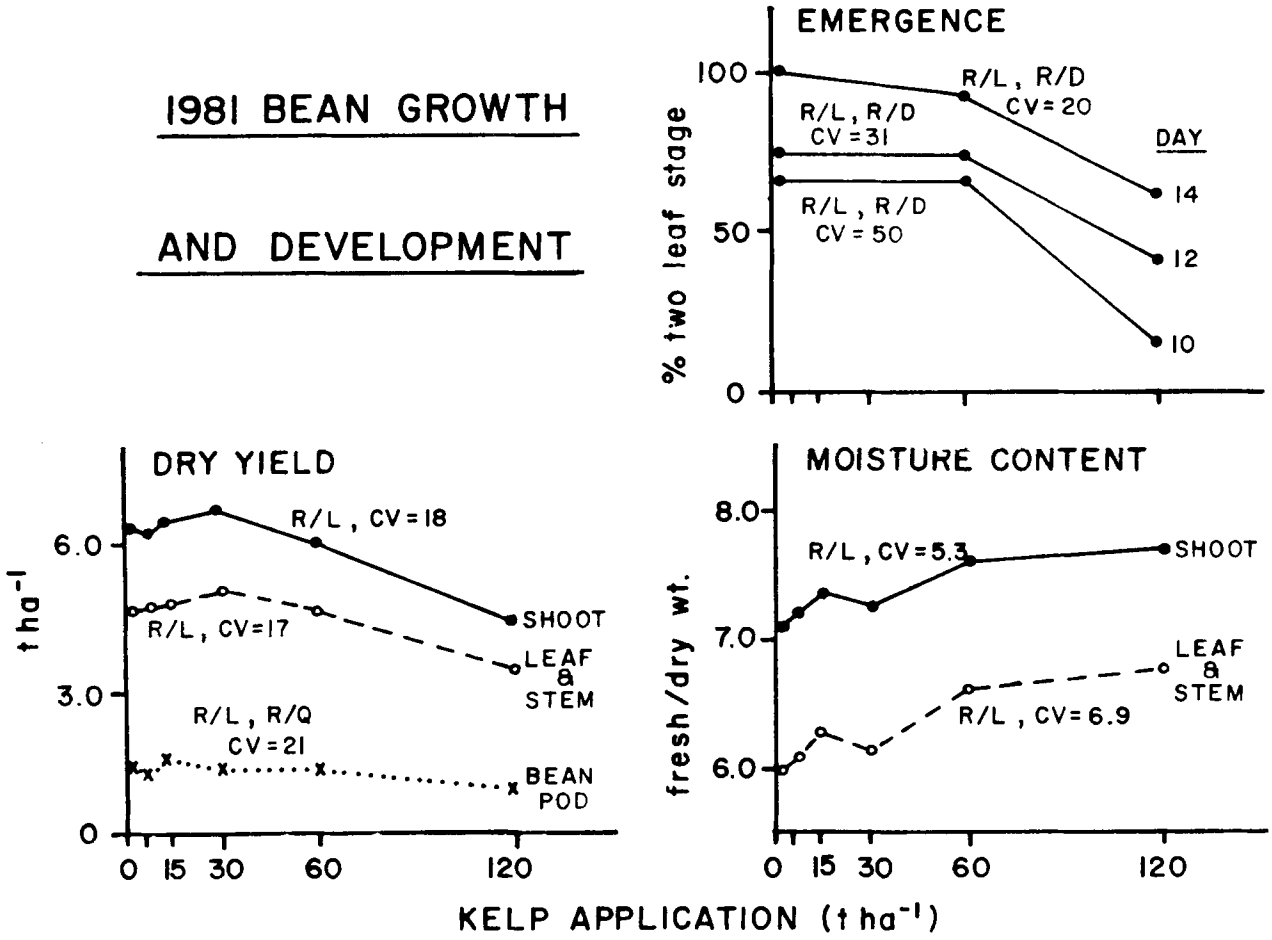

Fig. 1. 1981 field trial bean growth and development.

affected was dry pea leaf plus stem yields, which decreased with increasing kelp application (Table 2).

Increasing kelp applications resulted in significant increases in bean leaf plus stem N, K, Cl, Fe and Zn at harvest of the first growing season (Table 3). Na and K concentrations were increased in the pea leaf plus stem foliage at harvest in the second year (Table 2). Increasing kelp application also resulted in significant increases in the bean pod tissue concentrations of N, Mn and Zn (Table 3).

Soil chemical effects

Increasing quantities of kelp significantly in-

Table 2. 1982 Field trial pea growth or elemental concentration

Kelp application (t ha^{-1}):	0	7.5	15	30	60	120	Significant trend effect	CV
Growth response:								
Dry leaf and stem (t ha^{-1})	3.29	3.11	3.26	3.25	3.16	2.71	R/L	12
Elemental concentrations:								
Harvest (leaf and 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

Table 3. 1981 Field trial bean elemental concentrations

Kelp application ($t\,ha^{-1}$):	0	7.5	15	30	60	120	Significant trend effect	CV
Harvest (leaf and stem):								
N(%)	2.84	2.75	2.83	2.71	2.95	3.12	R/L	7.3
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):								
N(%)	2.71	2.77	2.02	2.82	2.88	2.98	R/L	5.6
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

creased soil EC, NO_3-N and soluble Cl and decreased soil pH in the 0–20 cm layer eight days after application (Table 4, preseeding 1981). 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. Kelp applications continued to have an effect on soil NO_3-N, soluble Cl and EC until pre-seeding 1982.

The soil exchangeable K, Mg, Na and Mn at

Table 4. 1981 and 1982 field trial 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 (H_2O)	5.7	a	a	a	5.1	5.2	R/L	9.2
Soluble Cl ($mg\,kg^{-1}$)	140	a	a	a	1000	1000	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 (H_2O)	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	1.50	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
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	0.45	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	0.10	0.13	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

[a] Not sampled.

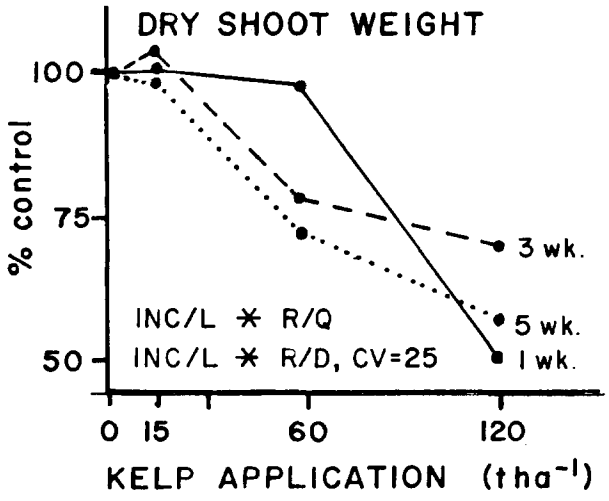

Fig. 2. Greenhouse experiment I (application * incubation) shoot dry weight.

harvest 1981 increased linearly with increasing kelp applications. Linear increases for exchangeable Mn, Na and K were recorded at pre-seeding and harvest 1982. 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 or approximately twice the soil porosity during the October to April (inclusive) period of 1981 to 1982.

Greenhouse experiments

The daily means of ambient relative humidity of Experiment I and Experiment II were 75% and 65%, respectively. Average daily maximum temperatures for Experiment I and Experiment II were 26 °C and 33 °C, respectively. Nightly minimum temperatures were 18 °C for both experiments.

Experiment I. Similar to the field trial, plant emergence decreased with increasing kelp applications as soil EC and Cl concentrations increased (data not presented). As was the case in the field trial, increasing kelp applications reduced bean emergence, shoot and bean yields and increased the moisture content of the shoot and bean pods (data not presented).

Incubation period had no effect on bean yields, but shoot responses to kelp application were slightly modified by the length of the kelp incubation period in the soil. After three or five weeks incubation, shoot yields were reduced by either 60 or 120 t ha^{-1}, however a reduction only occurred with the highest application rate after one week incubation (Figure 2).

Experiment II. Plant emergence was greater with leached soil than unleached soils (Figure 3). The leaf symptoms observed in the field trial 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 the 120 t ha^{-1} kelp application decreased yields in unleached soils (Figure 3). 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.

Discussion

Eight days after field application of kelp, *M. Integrifolia*, sharp linear increases in soil soluble salts (EC) and Cl and a decrease in pH were recorded. Bean crop emergence, and yields were reduced with 120 t ha^{-1} of kelp. Plants which received the 120 t ha^{-1} application were dark green and stunted, which according to Hajrasuliha (1980) is characteristic of Cl toxicity. Maas and Hoffman (1977) have also recorded similar growth effects with beans grown in salt solutions. According to Levitt (180) both drought and salt stress cause plant dehydration and plants have adapted several mechanisms to tolerate these conditions. 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) salt stress increases plant moisture content of beans (*P. vulgaris*) In this investigation, both crop K concentration and moisture contents increased as kelp additions increased soil levels of soluble salts (EC) and exchangeable K.

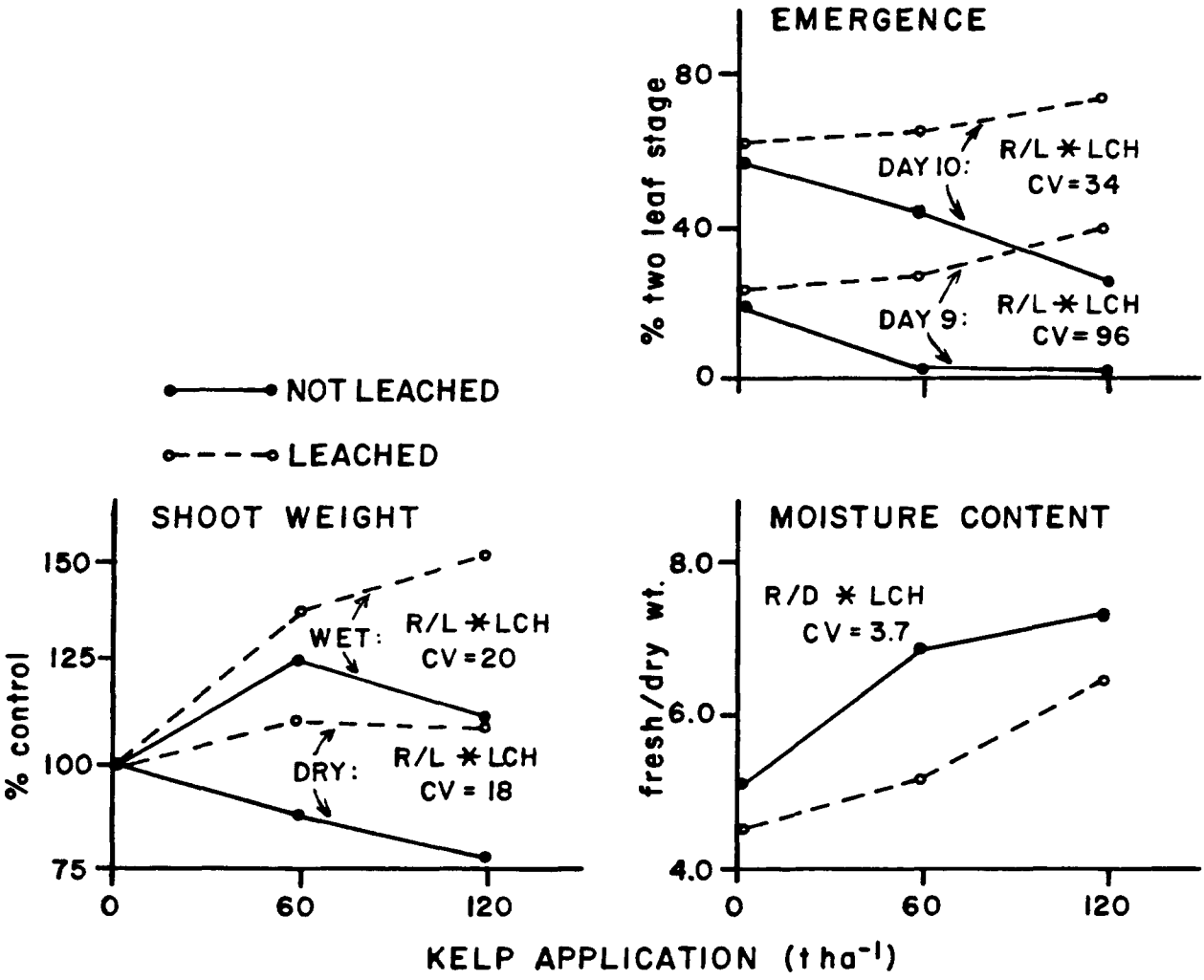

Fig. 3. Greenhouse experiment II (application * leaching) bean growth and development.

Nutrient availability (Jansson, 1971) and 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. In the greenhouse investigation (Experiment I) bean plant response to the quantity of kelp applied was influenced by the length of time between kelp incorporation into the soil and seeding. The one-week incubation 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 applications. These results suggest that apart from increasing quantities of kelp, other growth inhibiting mechanisms are implicated in reducing shoot yields. The apparent lag time in this phytotoxic response may be related to salt diffusion into the soil or biotic release of toxins with time. The 11.9 C/N ratio of this kelp makes nitrogen immobilization an unlikely cause of the shoot yield effects with increasing incubation period. The dominant influence on bean pod growth, however, was related to quantities of kelp applied, since incubation did not affect this variable.

Greenhouse 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 generally chlorotic or N deficient at flowering. Shoot dry weights at flowering were slightly affected 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. Leaching the soil also reduced the soil acidity, which implies that some of the measured soil acidity may have been salt induced. This greenhouse study does indicate that leaching will remove the growth-inhibiting effects of kelp applications up to 120 t ha^{-1} and that many of the crop growth responses in this field experiment were primarily related to increasing soil salt stress with increasing kelp applications.

The kelp's Na concentration (2.82 %) and subsequent addition of Na to the soil with increasing applications increased the field soil exchangeable Na and Na concentration of pea leaf plus stem plant tissue, but not in the bean tissue. Beans have been reported to retain Na in the roots and basal portions of the stems (Jacoby, 1964) and to efflux Na from their roots in an effort to avoid Na toxicity (Lessani and Marschner, 1978). In the second year, pea dry leaf plus stem yields were reduced in response to increasing applications of kelp. The increases in the leaf plus stem Na concentrations and decreasing shoot Na uptake (data not presented) with kelp application greater than 60 t ha^{-1} suggest that Na toxicity may have occurred with increasing kelp applications.

The increases in foliar concentrations of Fe, Zn and Mn with kelp application may simply be related to reduced dry matter production, rather than increased availability. Maas *et al* (1972) have demonstrated a positive correlation between plant concentrations of Fe, Mn and Zn with high salt-induced osmotic potentials of the growth media.

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*, which had received one to four fresh water leachings lost 23 % of its total N after one 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 from the kelp.

The kelp, *M. integrifolia*, used as a soil amendment in this investigation resulted in increases in soil N, K 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 inhibit the growth of salt sensitive crops. Caution is in order when large quantities of kelp are applied immediately prior to seeding. In addition, residual effects of kelp-derived soluble salts may be higher in other areas where low winter rainfall may not consistently leach salts from soils with adequate internal drainage.

Conclusions

Application of the fresh kelp, *M. integrifolia*, to a fine-textured soil at quantities up to approximately 60 t ha^{-1} one week prior to seeding increased bean yield; however, the 120 t ha^{-1} soil application rate reduced emergence and bean yields. There was some residual effect on pea growth and nutritional responses in the second season one year after kelp application. The reduced emergence and yields that were measured with the large (120 t ha^{-1}) kelp applications appear to be mainly related to salt or Cl toxicity, although 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 of salt toxicity. Soil NO_3-N, K, Mn, Na, Cl and EC increased linearly with increasing applications. 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.

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