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Effect of seaweed concentrate on hydroponically grown spring barley

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Abstract

Spring barley (*Hordeum vulgare* cv. Triumph) was grown hydroponically over a 6-week period. Two treatments were incorporated either into the hydroponic solution or sprayed onto the plants at rates of 1 ml per 3 litres. The treatments applied were: (i) a seaweed concentrate prepared from *Ascophyllum nodosum* (L.) Le Jolis (marketed as Maxicrop Triple), (ii) a 'Trace element' treatment incorporating the micro and macro nutrients added to the seaweed extract base to produce the formulated product Maxicrop Triple and (iii) a control treatment. Irrespective of the mode of application, plants treated with Maxicrop Triple grew faster than plants under either of the two other treatments. Elevated growth rates were also found for the 'Trace element' treated plants when incorporated into the hydroponic solution. At the final harvest, plants with Maxicrop Triple incorporated into the hydroponic solution showed increases from 56–63% over the control treatment for the growth characteristics measured. 'Trace element'-treated plants produced increases of between 25–45%. When the treatments were sprayed the effect was less pronounced. Maxicrop Triple increased growth characters by 35–38% and the 'trace element' treatment gave increases in the range of 2–13%.

Introduction

Recently a number of reports have been written suggesting that the application of seaweed extracts to crop plants can increase yield. Tests have taken place on a wide variety of species, but how these increases are produced is not clear (Abetz & Young, 1983; Blunden *et al.*, 1979; Featonby-Smith & Van Staden, 1983). It has been suggested that trace elements present in the extract mediate the enhancement, but Blunden (1977) considers that the level of trace elements in the commercial product is too low to account for the increased growth observed. As long ago as 1966 Booth suggested that plant hormones, particularly the cytokinins might be implicated. Cytokinins have been detected in both marine algae (Hussein & Boney, 1969) and in extracts prepared from marine algae (Brain *et al.*, 1973; Featonby-Smith & Van Staden, 1983). The application of cytokinins to growing plants has been shown to mimic certain of the effects observed when seaweed extracts are similarly applied (Biddington & Dearman, 1983). Amongst recent reports the effects of seaweed extracts either as a root drench or foliar spray on the stimulation of root growth figure prominently (Blunden & Wildgoose, 1977; Biddington & Dearman, 1983;

Finnie & Van Staden, 1985; Nelson & Van Staden, 1984 a + b). Cytokinins were found to be most effective when applied to plants at an early stage of growth. The presence of cytokinins in the extract is almost certainly a potent factor in promoting an extensive root system thus setting a framework for increased yield. No consistency of view has held however with respect to the role of cytokinins in plant development. Stenlid (1982) and Biddington and Dearman (1983) observed an inhibitory effect of cytokinins on root extension whilst Torrey (1976) and Wrightman *et al.* (1980) showed a decrease in lateral root formation following cytokinin application. It was noted also by Torrey that auxin-induced lateral root production in isolated pea-root segments was enhanced by certain concentrations of kinetin. Finnie and Van Staden (1985) demonstrated that at low concentrations of zeatin (cytokinin), 10^{-6} M and below, root growth was promoted, but that above 10^{-6} M root growth was inhibited.

Cytokinins have been implicated also as a 'shoot factor' which is transported from the site of synthesis in the roots, to the shoots, where they are active in the regulation of protein levels in the leaves (Chibnall, 1939).

The experiments considered here were designed to demonstrate whether a liquid seaweed extract, Maxicrop Triple, would stimulate growth in barley seedlings grown under hydroponic conditions.

Materials and methods

Barley seed (*Hordeum vulgare* cv Triumph) was planted in perlite, pre-soaked with distilled water. Perlite was used as a planting medium because of its sterile inert characteristics. To ensure that plants received no mineral supplementation they were watered with distilled water. One week later, after development of the first two leaves (Growth Stage 1, Large), seedlings of a similar size were transplanted into trays cut from polystyrene sheet into which a grid of holes had been cut 1 cm^2 in diameter. This gave a density equivalent to 700 plants m^2 when one seedling was planted per hole. The trays were floated on the surface of plastic bowls (37 × 31 × 13 cm) which contained the hydroponic solution. The bowls were each filled with 6 litres of standard solution designed for the hydroponic culture of the gramineae. In the first experiment the treatments were added to the bowls, in the second treatments were sprayed onto the leaves. Treatments were applied weekly and, following treatments, the bowls were re-randomised. In each experiment the same three treatments were used: Maxicrop Triple (dilution rate 1:3000), a 'Trace element' treatment (containing all micro and macro elements added to formulate the product Maxicrop Triple) and a distilled water control. Two bowls were used for each treatment. An air pump running at the rate of 1 bubble per second oxygenated the solution continuously. The hydroponic solution was changed weekly and the treatments reimposed. The experiment was conducted in a growth room set to produce a constant temperature of 21 °C and a daylength of 14 h. The initial sample was taken on the first day of the experiment, when the bowls were being planted up with the barley seedlings. Twenty plants were sampled and dry weights were taken for root, shoot and leaf weights. Leaf area measurements were also taken. Thereafter, twenty plants were removed from each treatment sequentially across the planting grid at each weekly sampling, care being taken to ensure that the roots were not damaged in the process. Each plant was separated into root, shoot and leaf material. Leaf area was measured using a Crump 600 portable leaf area index machine. All material was then bagged separately and dried at 30 °C for 3 days before weighing. The duration of each experiment was 6 weeks.

Results

Although the two experiments were conducted at different times it is more convenient to consider the results obtained jointly. Furthermore, each set of results is described, first of all on the basis of plant growth over the 6-week period and then for that at final harvest.

Rates of growth: Treatments incorporated into the hydroponic solution

The data obtained for all weekly samplings were transformed into natural logarithms and subjected to linear regression analysis. The best fitting line was calculated from the mean values estimated over the course of the experiment for each treatment (Fig. 1). Regression coefficients estimated from the data were tested for significance and are given in Table 1.

In each case the overall heterogeneity between regression coefficients was highly significant as were the differences between treatment pairs ($P<0.001$). Plants treated with Maxicrop Triple (b_1) grew at a faster rate than either the 'Trace

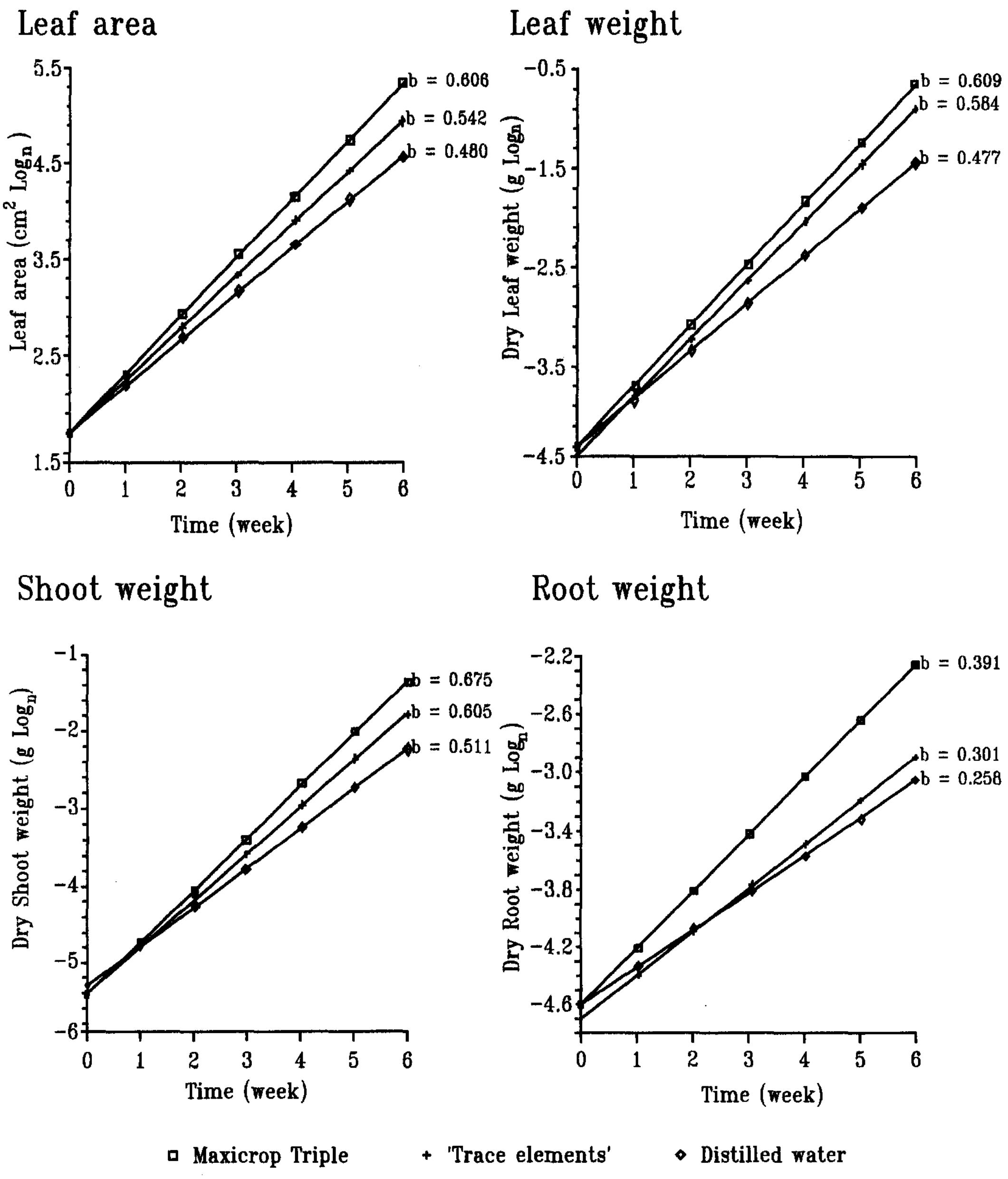

Fig. 1. Growth characteristics of Triumph spring barley grown in a hydroponic system with treatments added to the solution.

Table 1. Analysis of regression coefficients and tests of significance between relative growth rate (b values) for each treatment difference (Treatments incorporated). b_1 = Maxicrop Triple; b_2 = 'Trace element'; b_3 = Distilled water. All figures significant at $P<0.001$ level.

	Heterogeneity of regression coefficients	Difference between regression Coefficients			
		b_1–b_2	b_1–b_3	b_2–b_3	S.E.
Leaf area (cm^2)	44.26	0.0645	0.1273	0.0627	±0.011
Leaf weight (g)	59.70	0.0452	0.1323	0.0878	±0.012
Shoot weight (g)	93.71	0.0697	0.1643	0.0946	±0.012
Root weight (g)	95.09	0.0891	0.1349	0.0458	±0.009

element' (b_2) or the Distilled water control group (b_3). The 'Trace element' group nevertheless grew at a significantly higher rate than the control group.

Rates of growth: Treatments sprayed onto plants growing in a hydroponic solution

The growth characteristics of Spring Barley when the treatments were sprayed onto the plants are shown in Fig. 2 and the tests of significance between the relative growth rates in Table 2. Maxicrop Triple sprayed onto the leaves led to increased rates of growth in both root and shoot whereas, apart from a modest increase in root weight compared to the control, the spraying of trace elements onto the plants gave no positive increase in growth rate.

Rates of growth: Comparison between treatments incorporated into hydroponic solution or sprayed onto leaves

In both experiments regardless of whether treatments were added to the growing medium or sprayed onto the leaves, the Maxicrop Triple treatment consistently produced plants which grew at a higher rate than those from either of the other two treatments groups. This suggests that a substance contained in the Maxicrop Triple liquid stimulated growth beyond that contributed by the inorganic nutrients present.

The 'Trace element' treatment was designed to represent the inorganic elements present in Maxicrop Triple. When this treatment was added to the growth medium it produced increased rates of growth when compared to the control plants indicating that part of the enhancement produced by Maxicrop Triple was due to its mineral com-

Table 2. Analysis of regression coefficients and tests of significance between relative growth rate (b values) for each treatment difference (Treatments sprayed). b_1 = Maxicrop Triple; b_2 = 'Trace element'; b_3 = Distilled water. All differences other than those between b_2–b_3 significant at $P<0.001$.

	Heterogeneity of regression coefficients	Difference between regression coefficients			
		b_1–b_2	b_1–b_3	b_2–b_3	S.E.
Leaf area (cm^2)	9.65	0.0630	0.0617	−0.0013	±0.016
Leaf weight (g)	21.74	0.0591	0.0742	0.0152	±0.012
Shoot weight (g)	26.74	0.0663	0.0704	0.0041	±0.011
Root weight (g)	24.93	0.0497	0.0748	0.0251	±0.011

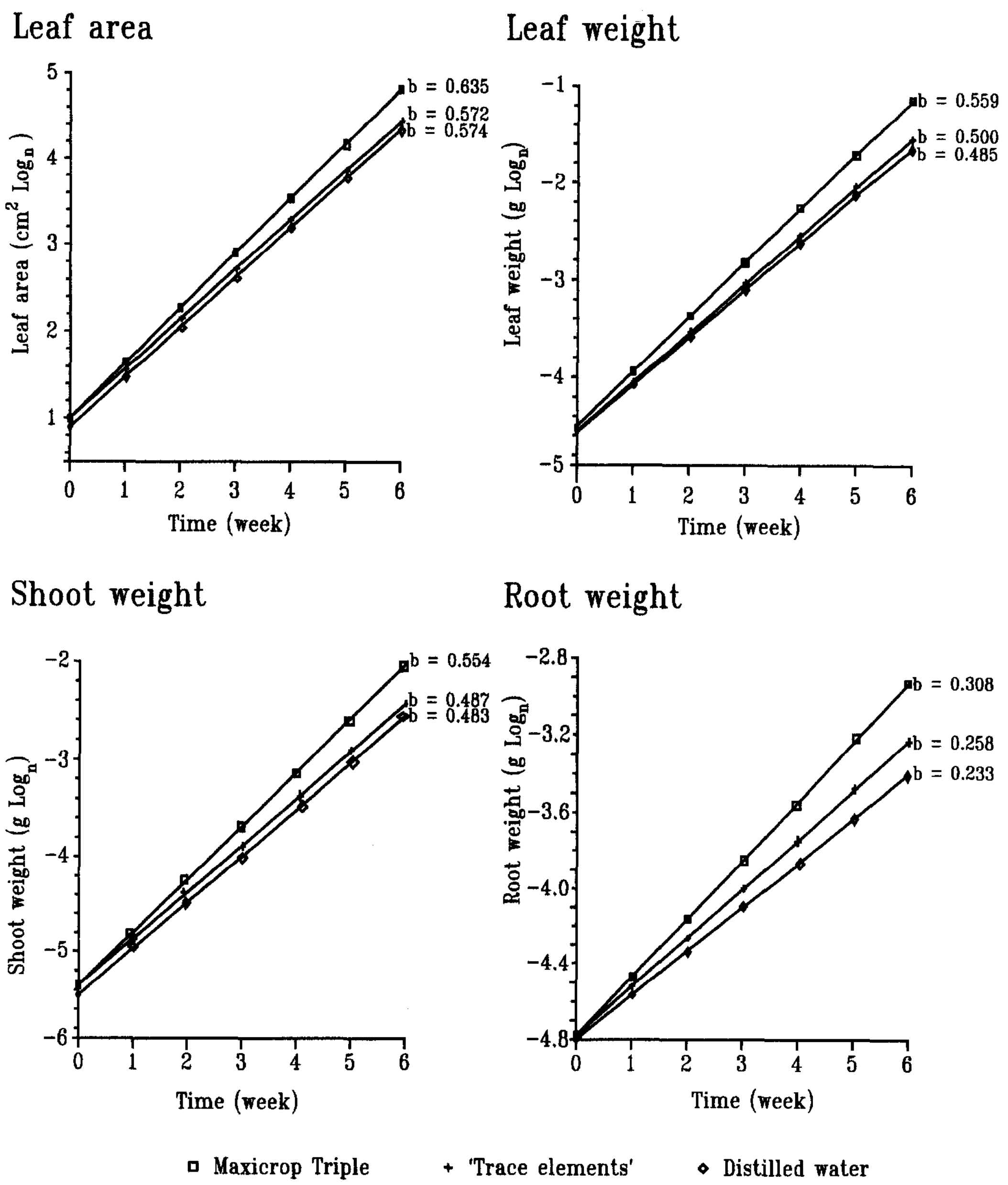

Fig. 2. Growth characteristics of Triumph spring barley grown in a hydroponic system with treatments sprayed onto plants.

ponents. However, when the 'Trace element' was applied in the form of a spray no significant increase over the distilled water control was observed, other than for root weight.

Whilst both experiments produced similar results the magnitude of the response differed. This may be illustrated by a consideration of measurements made at the final harvest (week 6).

Final harvest: Treatments incorporated into the hydroponic solution

Mean plant values based on the measurements of 20 plants per treatment at week 6 are given in Table 3. Treatment differences are expressed as both actual and percentage values.

At final harvest the leaf area, leaf weight and

Table 3. Effects of seaweed concentrate applied in a nutrient solution (week 6, $n = 20$). T_1 = Maxicrop Triple; T_2 = 'Trace element'; T_3 = Distilled water. Percentage increase in parentheses

Item	Mean values			Treatment differences			
	T_1	T_2	T_3	T_1 v T_2	T_1 v T_3	T_2 v T_3	S.E.
Leaf area (cm^2)	208.9	146.5	81.2	62.4 (77)	127.6 (157)	65.3 (80)	±6.50
Leaf wt (g)	0.412	0.290	0.168	0.122 (73)	0.244 (145)	0.122 (72)	±0.013
Shoot wt (g)	0.221	0.152	0.081	0.069 (85)	0.139 (172)	0.070 (87)	±0.007
Root wt (g)	0.106	0.063	0.047	0.043 (90)	0.059 (125)	0.016 (34)	±0.003

shoot weight of Maxicrop Triple treated plants showed highly significant increases ranging from 145–172% above those of the control values whilst the response to 'Trace element' incorporation was only half as much. The 'Trace element' treatment nevertheless produced increases of between 72–87% compared to the control. In the case of root weight, a similar percentage increase to that seen for the aerial parts was obtained when Maxicrop Triple was incorporated into the hydroponic solution, but the margin of difference between the Maxicrop Triple and 'Trace element' treatments increased, 125% compared to 34%.

Final harvest: Treatments sprayed onto plants grown in a hydroponic solution

From Table 4 it can be seen that again there are highly significant differences between treatments ($P < 0.001$). Maxicrop Triple, when sprayed onto the leaves, stimulated growth between 55–62% compared to the control and gave an increase of between 41–56% when compared to the 'Trace element' treatment. Spraying 'Trace elements' failed to increase leaf area and had a marginal effect only on leaf and shoot weight (6–7%). When 'Trace elements' were sprayed onto the aerial plant parts they produced a greater response in root growth than in shoot growth.

Final harvest: Comparison between treatments incorporated into the hydroponic solution or sprayed onto leaves

Comparison of the mean values in Tables 3 and 4 shows that the spraying treatments produced much smaller plants. The control plants gave similar values under both application regimes whilst values for both the Maxicrop Triple and 'Trace element' treatments were more than doubled when incorporated into hydroponic solution. It was the 'Trace element' treatment that gave the greatest discrepancy between the two modes of application, 72–87% when incorporated opposed to 2–7% when sprayed, suggesting that applied nutrients were not penetrating the leaf effectively.

Table 4. Effects of seaweed concentrate sprayed onto the leaves of barley plants (week 6, $n = 20$). T_1 = Maxicrop Triple; T_2 = 'Trace element'; T_3 = Distilled water. Percentage increase given in parentheses

Item	Mean values			Treatment differences			
	T_1	T_2	T_3	T_1 v T_2	T_1 v T_3	T_2 v T_3	S.E.
Leaf area (cm^2)	93.2	61.6	60.2	31.7 (53)	33.0 (55)	1.4 (2)	±0.892
Leaf wt (g)	0.224	0.148	0.138	0.078 (56)	0.086 (62)	0.009 (7)	±0.003
Shoot wt (g)	0.096	0.063	0.059	0.033 (55)	0.036 (61)	0.004 (6)	±0.001
Root wt (g)	0.053	0.039	0.034	0.014 (41)	0.019 (57)	0.005 (15)	±0.001

Discussion

In seedling plants there is a transition from dependence upon food reserves to the photosynthetic activity of the leaf. Seedlings of wheat for example become independent following the full extension of the 2nd leaf and the emergence of the 3rd. To achieve maximum rates of growth seedlings rely upon an external source of nutrients. Considerably more reserves are being mobilised and diverted to root growth rather than to leaf growth. In the developmental sequence within the seedling, independence for the uptake of minerals and water is established before photosynthetic capacity is fully developed. It is not unreasonable to assume that the physiological efficiency of the root system depends upon both the extent of its absorptive surface and its effective duration. Furthermore, considerable advantage will accrue to those individuals within a population that develop precociously. The beneficial effects of seaweed concentrate applied to plants during early growth in this case is in accord with findings by Featonby-Smith and Van Staden (1983, 1984) for beans and tomatoes. Whether added to the hydroponic solution or applied as a spray the Maxicrop Triple treatment advantage became more pronounced with time so that at final harvest plants were superior in all growth characteristics measured compared to the two other treatments. To some extent, previous attempts to dismiss the utility of seaweed concentrates by crediting their effects to the nutritional supplementation of the natural product may be discounted. Note that here, whilst direct application to the roots with mineral supplementation equivalent to the levels applied in Maxicrop Triple increased growth, the increase was less than that obtained by plants treated with Maxicrop Triple. Furthermore, foliar application of 'Trace element' supplements failed to produce significant increases in plant growth. Nonetheless the active components of the seaweed concentrate remain to be elucidated. Several groups of compounds present in the seaweed extract could be responsible for the stimulation of growth observed, although the cytokinins are currently considered the most likely group. Cytokinins have been shown to promote root growth at low concentrations 10^{-6} M – 10^{-8} M (Wrightman *et al.*, 1980). The commercial product tested here has been shown to contain cytokinins within this range and there is substantial evidence to show that the growth and development of the aerial parts of plants are dependent upon hormones synthesised by the roots. The early promotion of the root system must be of considerable benefit therefore. It is concluded that commercially applied rates of seaweed concentrate have a beneficial effect upon the early growth of barley plants, whether used as a solution in direct contact with the roots or applied as a foliar spray. Moreover these effects are not dependent upon the addition of macro- and micro-elements.

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