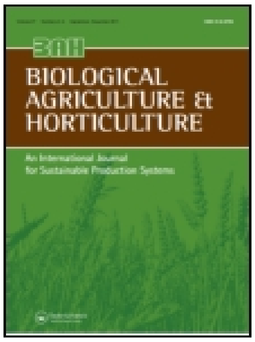

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The effect of kelp extract on seedling establishment of broccoli on contrasting soil types in southern Victoria, Australia

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This study investigated whether kelp extract from *Durvillaea potatorum* and *Ascophyllum nodosum* (Seasol Commercial®) stimulates broccoli establishment and growth. Under controlled conditions in the glasshouse, weekly applications of kelp extract significantly increased the leaf area, stem diameter and biomass of broccoli by up to 70%, 65% and 145%, respectively. Also in the glasshouse, lower strength dilutions of kelp extract (1:200 to 1:500) were most effective in stimulating early growth of broccoli, whereas higher strength dilutions (1:25 to 1:100) were most effective later in plant development. In the field, application of kelp extract as a drench to a clay-loam soil (Sodosol) significantly increased the leaf number, stem diameter and leaf area of establishing broccoli seedlings by 6%, 10% and 9%, respectively, irrespective of application rate (three applications at 2.5 or 25 l ha^{-1}). Furthermore, kelp extract significantly reduced the early incidence of white blister, caused by *Albugo candida*, on broccoli by 23%. In a sandy soil (Podosol), the effect of kelp extract was less pronounced, with only the leaf area of broccoli seedlings increasing significantly following treatment with kelp applied at the highest rate. It is hypothesized that differences in cation exchange capacity, organic matter and/or leaching properties contribute to variation in the response of broccoli to kelp extract in different soils. Future research is proposed to examine the capacity of kelp extract to offset the high nutrient inputs needed at establishment in the broccoli industry.

Keywords: *Albugo candida*; *Ascophyllum nodosum*; *Durvillaea potatorum*; Seasol®; seaweed extract

Introduction

Southern Victoria is the largest growing region for broccoli in Australia, producing more than 22,000 tonnes annually, which is worth A$50 million on the domestic market (Hortstats 2013). Like many regions worldwide, growers apply high rates of nitrogen (N) fertilizers (75–220 kg N ha^{-1}) at transplanting or soon after (Dimsey 2009), which are critical for stimulating early growth of seedlings and, in turn, high commercial yields (Thompson et al. 2002; Feller & Fink 2005; Yoldas et al. 2008; Bakker et al. 2009). These high nutrient inputs make broccoli systems prone to N losses through leaching and volatilization (Feller & Fink 2005; Bakker et al. 2009; Porter et al. 2012), and can have detrimental impacts on the environment, such as nitrate flows into waterways and increased greenhouse gas emissions of nitrous oxide. The accumulation of high levels of nitrates in brassica crops can also impact adversely on human health (Luo et al. 2006; Parks et al. 2008). These factors are driving the consideration of

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alternative methods for stimulating early growth in broccoli, and potentially to offset or enhance the effectiveness of fertilizers and other synthetic cropping inputs.

Previous research has shown that kelp extracts can increase the early growth of brassicas and other vegetable crops. Aldworth and van Staden (1987) found that dipping cabbage seedlings in a kelp extract from *Ecklonia maxima* reduced transplant shock and increased their biomass by 33% at 4 weeks after planting. Furthermore, Abetz and Young (1983) showed that drenches with a kelp extract from *Ascophyllum nodosum* increased the curd size of cauliflower in southern Victoria. More recent studies in other cropping systems support the potential for kelp extracts to increase early growth, and attribute the mechanism to a complex action of growth regulators, particularly cytokinins and auxins, betaines, sterols and organic polymers (Verkleij 1992; Kahn et al. 2009; Craigie 2010). For example, using an extract from *Durvillaea potatorum* (Seasol®), Tay et al. (1985, 1987) pioneered the discovery of a range of cytokinins in kelps, including isopentyl-adenine, zeatin, dihydrozeatin, and their corresponding 9-β-D-ribosides and *O*-glucosides. Soybean bioassays with these compounds provided evidence that they contribute to the stimulatory effect of this extract on plant growth. It is noteworthy that exogenous application of some cytokinins in the field has increased broccoli (Singh et al. 2011) and cauliflower (Abetz & Young 1983) yields by up to 27%.

Several authors consider that agricultural and horticultural industries have not fully exploited and adopted kelp extracts in their production systems (e.g. Kahn et al. 2009; Quilty & Cattle 2011). To achieve this will require greater understanding of the mechanisms involved and applied knowledge to improve the consistency of crop responses to kelp extracts. Information on optimal application dilutions, rates, timing and methods needs development for specific crops, geographical locations and environments (Craigie 2010). For example, few studies have examined the effects of kelp extracts in different soil types. Pant et al. (2011) found that a compost tea fortified with kelp extract increased the growth of pak choi in an Oxisol soil, but not in a Mollisol soil. They postulated that this was due to the poor drainage of the Mollisol, which suppressed root development and resulted in an accumulation of salts following treatment. In addition, it is important to recognize that commercial kelp extracts and their properties differ with the species of the kelp utilized and with commercial extraction systems (Verkleij 1992).

This study examined the hypothesis that additional application of kelp extract from *D. potatorum* and *A. nodosum* stimulates broccoli establishment and growth above that achieved with standard industry practices. The study also aimed to identify the effects of dilutions of this kelp extract, and application in different soil types in the field in southern Victoria, Australia, on broccoli establishment and growth.

Materials and methods

Glasshouse trial

A glasshouse trial was conducted to examine the effect of an alkaline hydrolysis extract from *D. potatorum* and *A. nodosum* [Seasol Commercial®, Seasol International (Bayswater, Victoria, Australia); 0.2% N, 0.02% P, 3.7% K, w/v] on the establishment and growth of broccoli (*Brassica oleracea* var. italica). Treatments included kelp extract in aqueous dilutions of 1:25, 1:100, 1:200 and 1:500 and distilled water as the control, equivalent to kelp extract concentrations of 4%, 1%, 0.5%, 0.2% and 0% (v:v), respectively. The trial was conducted as a randomized complete block design with four blocks. Measurements were taken from 15 or 5 replicate plants per treatment per block at the seedling establishment and plant growth phases, respectively.

Seedling establishment

Two hundred seeds of broccoli (cv. Marathon, Henderson Seeds, Templestowe Lower, Victoria, Australia) were placed in Falcon tubes (50 ml), covered with treatment solutions and allowed to imbibe for 16 h at 21°C in the dark. Commercial seedling trays (42 × 38 mm cells) were filled to an even level with pasteurized seed raising mix (Debco, Tyabb, Victoria, Australia). Imbibed seeds (48 seeds per tray) were planted into the seedling trays at a rate of one seed per cell. Trays were placed in a temperature-controlled glasshouse (15–24°C) and maintained at field capacity using an overhead micro-irrigation system. In addition, trays were drenched to through flow with treatment solutions at 3 days after sowing, and then every 5 days, using a watering can.

Seedling emergence was recorded daily from 3 until 7 days after sowing, and then a final measure at 14 days after sowing. At 6 weeks after sowing, seedlings were washed free of potting mix, and root and shoot lengths recorded.

Plant growth

At 6 weeks after sowing, five randomly selected seedlings were transplanted into pots (7.5 cm diameter) containing pasteurized potting mix (Banksia Nurseries, Knoxfield, Victoria, Australia). Pots were placed in the glasshouse and maintained at field capacity with a drip irrigation system. Drenches with the treatment solutions continued every week at a rate of 50 ml per pot to the point of through flow. In addition, 50 ml of 1/4 strength Hoagland's solution was applied weekly to all pots to maintain an environment of high nutrition. The area of the most expanded leaf was measured weekly from 4 weeks after transplanting when leaves were large enough to accurately measure. In this procedure, leaf length and breadth were measured, and leaf area was calculated based on the calibration described by Olfati et al. (2010). The accuracy of this calibration was previously confirmed by regression analysis of leaf area, determined by image analysis, and the length and breadth of 50 individual leaves of two broccoli cultivars, Marathon and Viper. At harvest, 10 weeks after transplanting, the stem diameters of plants were measured using an electronic calliper. Plants were then washed free of potting mix, separated into roots and shoots, placed in an oven for 4 days at 80°C and dry weights recorded.

Field trials

Two field trials were conducted on commercial farms to examine the effects of kelp extract from *D. potatorum* and *A. nodosum* (Seasol Commercial®, Seasol International) on the establishment of broccoli seedlings in contrasting soil types. One trial was performed at Werribee South, Victoria, Australia (37°56′02.1″S, 144°41′25.0″E), on a site with a clay-loam soil (Red Sodosol) and a brassica/lettuce crop rotation. A second trial was conducted at Boneo, Victoria, Australia (38°24′10.7″S, 144°54′08.0″E), on a deep sandy soil (Aeric Podosol) with a brassica/celery/silver beet/parsnip rotation. The soil properties prior to the trial at each site are listed in Table 1, with the major differences being that the Sodosol had a higher cation exchange capacity and organic matter content than the Podosol. Both sites had a history of white blister, caused by *Albugo candida*, in previous broccoli crops.

The trials were conducted as randomized complete block designs with four blocks. Treatments consisted of crop drenching with kelp extract at 25 and 2.5 l ha^{-1} or water at 25 l ha^{-1} (control). Individual plots were 9.1 m long × 1.62 m wide in the Werribee South trial and 10.6 m long × 1.62 m wide in the Boneo trial.

Table 1. Initial soil properties at two experimental sites used to investigate the effect of a kelp extract on transplant establishment of broccoli in southern Victoria.

	Field trial site	
Soil parameter	Werribee South	Boneo
Soil type	Red Sodosol	Aeric Podosol
Soil texture	Clay loam	Sand
pH (1:5 water)	8.30	7.47
CEC (Mequiv. 100 g^{-1})	12.55	6.70
EC (dS m^{-1})	0.14	0.16
Organic matter (%)	1.50	1.06
Nitrate (mg kg^{-1})	14.2	47.0
Ammonium (mg kg^{-1})	9.0	5.8
Phosphorus (mg kg^{-1})	237.0	302.5
Potassium (mg kg^{-1})	365	110

Note: CEC, cation exchange capacity; EC, electrical conductivity.

Prior to transplanting, commercial broccoli seedlings (cv. Viper) were soaked in a solution of kelp extract (1:200 dilution with water) or water (control) overnight. Seedlings were transplanted in two rows on raised beds (1.62 m wide) with plants within rows spaced 200 mm apart. A standard fertilizer program for broccoli production was used across both trials; a base application of Nitrophoska Special® (Incitec Pivot, Southbank, Victoria, Australia, 400 kg ha^{-1}, 12% N) at transplanting and top-dress applications of calcium nitrate (Yara, Sydney, New South Wales, Australia, 250 kg ha^{-1}, 15.5% N) or ammonium sulphate/nitrate (Incitec Pivot, 150 kg ha^{-1}, 26% N) at 14 days after transplanting and budding (total 126 kg N ha^{-1}). Following transplanting, treatments were applied directly over the seedlings in the planting rows with a watering can, and repeated every 10 days for a total of three consecutive applications (i.e. at 0, 10 and 20 days after transplanting). Crop irrigation was with overhead sprinklers using the growers' application schedule. The Werribee South trial was transplanted on 2 March 2011 and the Boneo trial on 16 March 2011.

At 0, 10, 20 and 30 days after transplanting, five centrally located plants per plot were measured for leaf number and stem diameter, using a digital calliper, and leaf area of the most expanded leaf, based on the calibration described by Olfati et al. (2010). In addition, the incidence of white blister on leaves (number of infected leaves/total number of leaves) was measured. An individual leaf was defined as infected if it contained ≥ 1 pustule of white blister. The growers at the two trials commenced fungicide programmes for white blister at 30 days after transplanting, so no further assessments of the impact of treatment were made past this date.

Data analysis

Data from all experiments were analysed by ANOVA using Genstat v. 12.1 (VSN International, Hemel Hempstead, UK). Homogeneity of variance was determined by examining plots of fitted values versus residuals, while histograms of residuals were examined for normality of distribution. Fisher's least significant difference test was used to identify differences between treatment means. The level of significance used was $p \leq 0.05$. Non-linear regression (XLSTAT v. 2013, Addinsoft, New York, NY, USA) was used to characterize the relationship between concentration of kelp extract and total dry weight of broccoli.

Table 2. Seedling emergence, at different days after sowing, of broccoli drenched in different dilutions of kelp extract (KE) in a glasshouse trial.

	Seedling emergence (%)					
Treatment	3 days	4 days	5 days	6 days	7 days	14 days
KE (1:25)	16.6 bc	35.0 bc	58.3 b	65.0 ab	66.6 ab	70.0 a
KE (1:100)	26.6 a	48.3 a	63.3 abc	63.3 abc	63.3 b	68.3 a
KE (1:200)	25.0 ab	46.6 ab	68.3 a	68.3 a	71.6 a	75.0 a
KE (1:500)	15.0 c	33.3 c	56.6 b	60.0 b	68.3 ab	70.0 a
Control (water)	20.0 abc	36.6 bc	60.0 b	65.0 ab	66.6 abc	70.0 a
LSD ($p = 0.05$)	8.6	11.6	8.1	7.4	7.3	7.2

Note: Values followed by different letters in each column are significantly different where $p \leq 0.05$.

Results

Glasshouse trial

Seedling establishment

Emergence of broccoli seedlings treated with kelp extract at dilutions of 1:100 and 1:200 was earlier than those treated with 1:25 and 1:500 dilutions, and the control (Table 2). This effect was statistically significant at 4 and 5 days after sowing, but dissipated over time. By 14 days after sowing, there was no significant difference in the number of seedlings emerging between treatments.

By 6 weeks after sowing, broccoli treated with the 1:200 kelp extract had significantly longer roots and total lengths (by 26% and 22%, respectively) than seedlings in the control (Table 3). Furthermore, treatment with all but the strongest dilution (1:25) of kelp extract significantly increased shoot lengths (up to 14%) compared with the control.

Plant growth

Initially, treatment with the non-commercial rate of 1:25 kelp extract suppressed the leaf area of broccoli compared with other kelp extract treatments (Figure 1). This effect, however, was no longer significant by 5 weeks after transplanting. At the end of the experiment (10 weeks after transplanting), plants drenched with 1:25 and 1:100 solutions of kelp extract had 70% larger leaf area (Figure 1), 65% thicker stems (Table 4) and 143% greater biomass (Table 4) than plants in the control. By comparison, plants drenched with commercially relevant

Table 3. Shoot and root lengths of broccoli seedlings, 6 weeks after sowing, drenched in different dilutions of kelp extract (KE) in a glasshouse trial.

	Seedling length (mm)		
Treatment	Shoot	Root	Total
KE (1:25)	53.3 b	160.4 ab	213.7 ab
KE (1:100)	62.1 a	147.3 ab	209.4 ab
KE (1:200)	61.5 a	166.9 a	228.4 a
KE (1:500)	59.2 a	158.7 ab	217.9 a
Control (water)	54.5 b	132.5 b	187.0 b
LSD ($p = 0.05$)	4.3	29.6	29.9

Note: Values followed by different letters in each column are significantly different where $p \leq 0.05$.

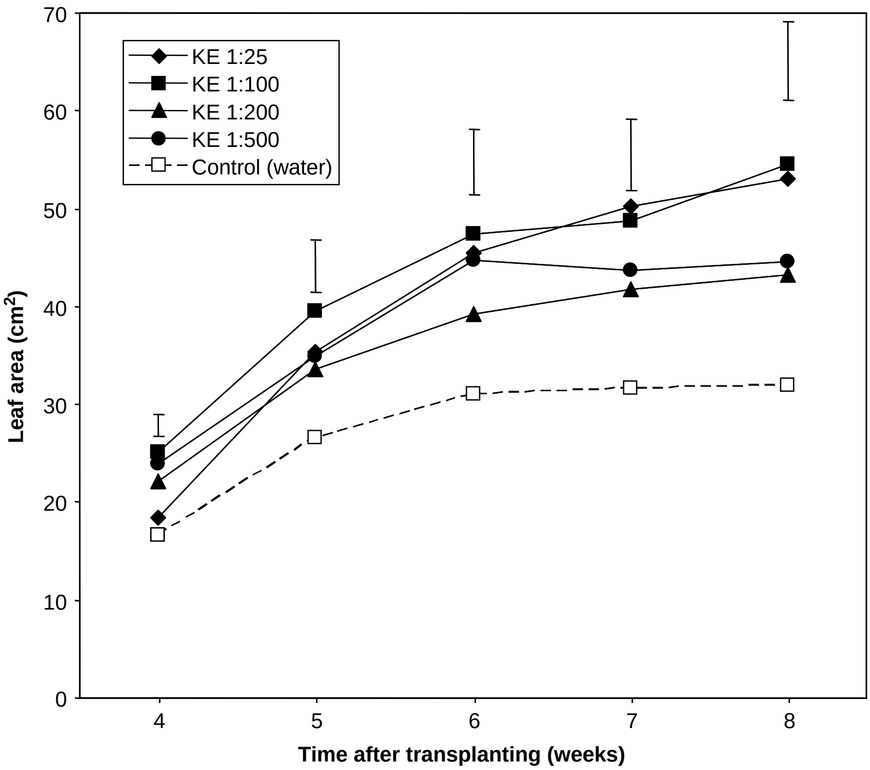

Figure 1. Leaf area of the most expanded leaf of broccoli plants drenched in different dilutions of kelp extract (KE) in a glasshouse trial. Bars are least significant differences where $p = 0.05$.

Table 4. Stem diameters and dry weight of broccoli plants, 10 weeks after transplanting, drenched in different dilutions of kelp extract (KE) in a glasshouse trial.

		Dry weight (gram per plant)		
Treatment	Stem diameter (mm)	Shoot	Root	Total
KE (1:25)	7.03 a	1.953 a	0.395 a	2.348 a
KE (1:100)	7.22 a	2.152 a	0.439 a	2.591 a
KE (1:200)	5.95 bc	1.511 b	0.387 a	1.899 b
KE (1:500)	6.16 b	1.455 b	0.393 a	1.848 b
Control (water)	4.38 c	0.792 c	0.273 b	1.065 c
LSD ($p = 0.05$)	0.78	0.368	0.092	0.429

Note: Values followed by different letters in each column are significantly different where $p \leq 0.05$.

dilutions of kelp extract at 1:200 and 1:500 had 40% larger leaf area (Figure 1), 40% thicker stems (Table 4) and 78% greater biomass (Table 4; Figure 2) than plants in the control. A parabolic function [total dry weight (TDW) $= 1.06 + 1.52\sqrt{C} - 0.11C^2$] provided the best fit ($r^2 = 0.95$) for the relationship between the concentration of kelp extract (C) and TDW of broccoli (Figure 2).

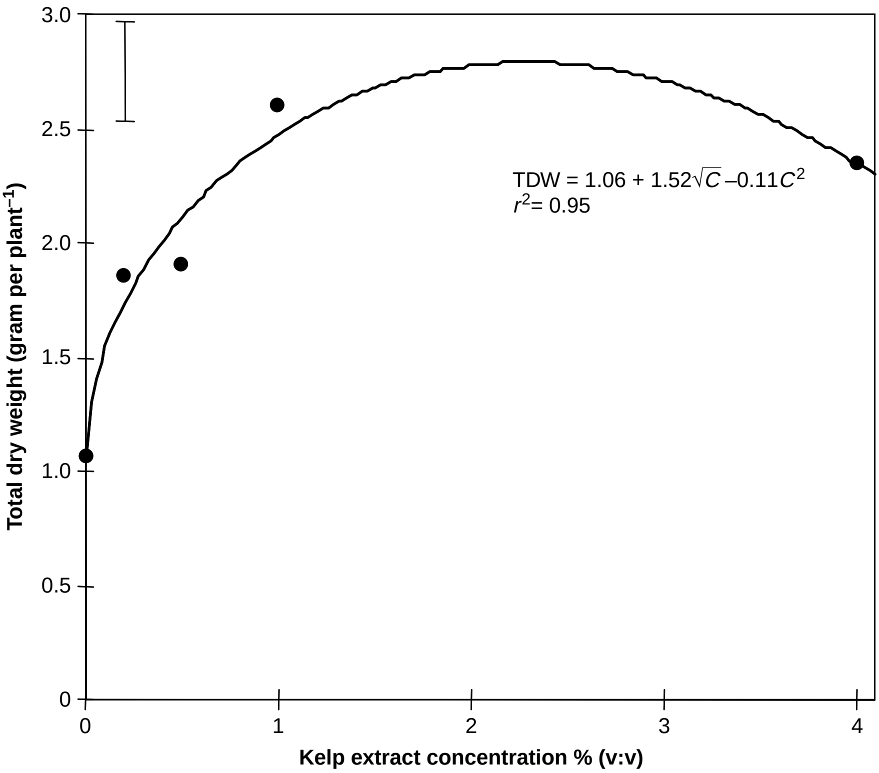

Figure 2. Observed and fitted relationship between TDW of broccoli and concentration of applied kelp extract in a glasshouse trial. The bar is the least significant difference, where $p = 0.05$, for comparing observed values.

Field trials

Seedling establishment

At the Werribee South site (Sodosol), kelp extract consistently increased the early shoot growth of broccoli seedlings compared with the control, with differences becoming more pronounced as time after transplanting progressed. At 30 days after transplanting, seedlings treated with kelp extract had 6% more leaves (Figure 3(a)), 10% thicker stems (Figure 3(c)) and 9% larger leaf area (Figure 3(e)) than plants in the control, irrespective of application rate.

The effect of kelp extract on broccoli seedling growth was less pronounced in the sandy Podosol soil at Boneo. At 30 days after transplanting, the high rate (25 l ha^{-1}) of kelp extract increased the leaf area of seedlings by 11% compared with the control, but the lower rate (2.5 l ha^{-1}) did not (Figure 3(f)). Under these soil conditions, kelp extracts did not affect leaf numbers (Figure 3(b)) or stem diameters (Figure 3(d)) of seedlings over the timeframe investigated.

Incidence of white blister

Symptoms of white blister, caused by *A. candida*, first appeared on broccoli seedlings at 20 days after transplanting at both trial sites. By 30 days after transplanting at the Werribee South site, the incidence of white blister on leaves was above 20% in the controls.

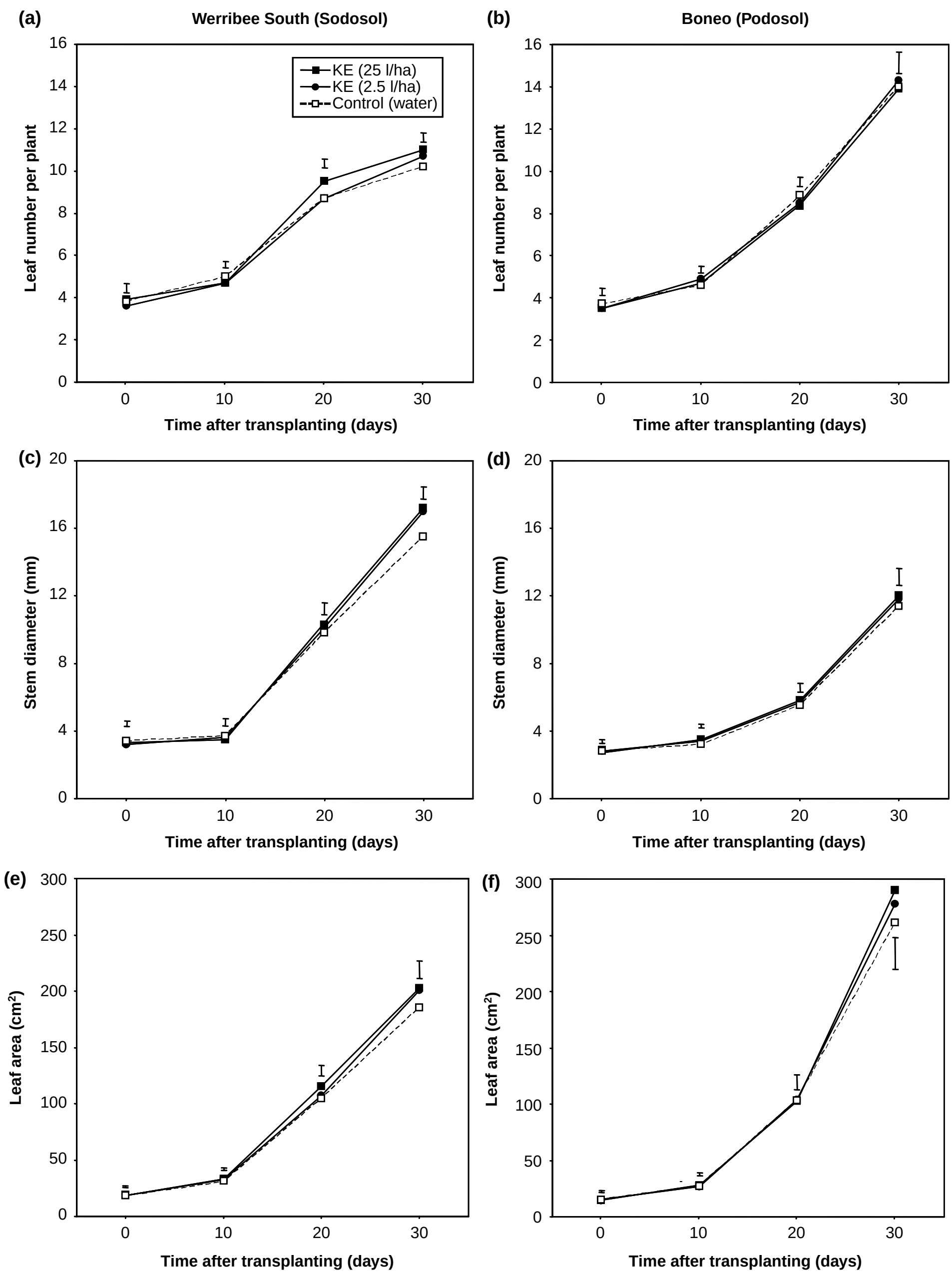

Figure 3. (a, b) Leaf numbers, (c, d) stem diameter and (e, f) area of the most expanded leaf of broccoli seedlings treated with kelp extracts (KE) and grown at two sites in southern Victoria (Werribee South (a), (c), (e); and Boneo (b), (d), (f)) with contrasting soil types. Bars are least significant differences where $p = 0.05$.

Application of kelp extract significantly reduced the incidence of white blister by up to 23%, irrespective of the application rate (Figure 4(a)). At the Boneo site, however, the incidence of white blister remained low (1% in the controls at 30 days after transplanting), and there were no significant differences between treatments (Figure 4(b)).

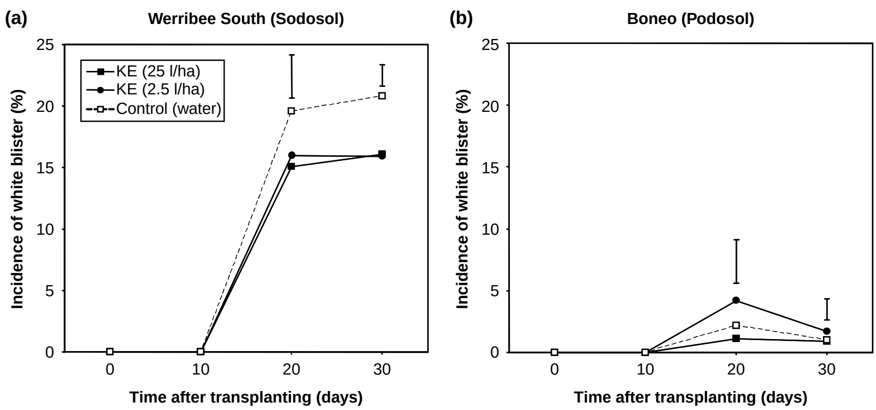

Figure 4. Incidence of white blister (%) caused by *Albugo candida* on broccoli seedlings treated with kelp extracts (KE) and grown at two sites in southern Victoria ((a) Werribee South; (b) Boneo) with contrasting soil types. Bars are least significant differences where $p = 0.05$.

Discussion

This study showed the capacity for a specific kelp extract from *D. potatorum* and *A. nodosum*, Seasol Commercial®, to stimulate the establishment, growth and health of broccoli seedlings in the glasshouse and field. Under controlled conditions in the glasshouse, application of the kelp extract accelerated emergence, and increased early root and shoot growth of broccoli seedlings at 42 days after sowing by up to 26% and 14%, respectively. In a related crop, da Silva et al. (2012) found that a different kelp extract from *A. nodosum* also increased the early (23 days after sowing) root and shoot biomass of cabbage seedlings by up to 50%. The enhanced root growth of seedlings treated with kelp extracts is significant because it can reduce transplant shock in vegetable crops (Aldworth & van Staden 1987; Crouch & van Staden 1992) and increase the potential for early nutrient and water uptake by the plant (Crouch et al. 1990; Mancuso et al. 2006). By comparison, Yusuf et al. (2012) found that a 1:600 dilution of the identical kelp extract used in this study increased the early root and shoot growth of pea by *c.* 60% and 25%, respectively. Control treatments in their experiment, which included nutrients and individual plant growth regulators (indole-3-butyric acid and 6-benzylaminopurine and gibberellic acid), did not increase root and shoot growth to the same extent as the kelp extract. Ashing the extract did not affect its capacity to stimulate shoot growth, but did cause a reduction in root growth probably due to the loss of organic compounds. This suggests that the mechanism of kelp extract from *D. potatorum* and *A. nodosum* in stimulating early seedling growth may involve a complex mixture of organic compounds, possibly including cytokinin and auxin growth regulators previously identified in the extract (Tay et al. 1985, 1987; Seasol International 2013). By the end of the glasshouse experiment in the current trial, weekly application of kelp extract markedly increased the leaf area and stem diameter, by up to 70% and 65%, respectively, and plant biomass, by up to 143%, of broccoli compared with the control.

Typically, the growth response of crops to kelp extracts is concentration dependent. For example, Finnie and van Staden (1985) showed that high concentrations (1:100 dilution) of a kelp extract from *E. maxima* inhibited the root growth of tomato, while low concentrations (1:600 dilution) stimulated it. In *Arabidopsis thaliana*, low concentrations ($0.1\,g\,l^{-1}$) of a kelp extract from *A. nodosum* stimulated root growth, but only high concentrations ($1\,g\,l^{-1}$) stimulated shoot growth (Rayorath et al. 2008). In the current study, lower concentrations of kelp extract (1:200 and 1:500 dilutions) stimulated the early growth of broccoli seedlings, while higher concentrations (1:25 dilutions) initially suppressed the shoot length and leaf area of establishing transplants. By the end of the glasshouse experiment, however, higher concentrations (1:25 and 1:100 dilutions) had increased plant biomass more than lower concentrations (1:200 and 1:500 dilutions). These results suggest that optimal concentrations for kelp extract from *D. potatorum* and *A. nodosum* for broccoli production may vary with plant development and need further investigation. The response of broccoli biomass to kelp extract concentration best fitted a parabolic function, as previously found for cabbage by da Silva et al. (2012). The response of broccoli biomass to the kelp extract reached a maximum above a threshold concentration of *c*. 1% (1:100 dilution). However, the effect of additional kelp extract concentrations needs investigation to validate this model, particularly around the inflection point, and to determine the exact concentration or combination of concentrations across plant development that optimizes broccoli production.

In the field, the response of commercial broccoli crops to kelp extract varied between the two sites with different soil types. At Werribee South on a clay-loam Sodosol, drenching transplants with kelp extract increased their shoot growth (leaf number by 6%, leaf area by 9% and stem diameter by 10%) over a 30-day period, irrespective of the application rate (three applications of 2.5 or $25\,l\,ha^{-1}$). This response is consistent with a study in a loam soil by Aldworth and van Staden (1987), which showed that dipping cabbage transplants in kelp extract from *E. maxima* increased their early shoot growth (stem diameter by 18% and shoot dry weight by 30%). A disproportionately earlier development and harvest of broccoli heads for those plants treated with the kelp extracts at the Werribee South site has also been shown by the authors (unpublished data). Similarly, tomato (Crouch & van Staden 1992) and capsicum (Eris et al. 1995; Arthur et al. 2003) have yielded earlier when treated with various kelp extracts, with evidence suggesting this may be due to cytokinins in the extracts mobilizing nutrients from the vegetative to reproductive organs of the plant (Kahn et al. 2009). In the current trials, the effects of kelp extracts were less pronounced at Boneo on a sandy Podosol soil than on the clay-loam Sodosol at Werribee South. Application of kelp extract at Boneo still increased the leaf area of establishing broccoli seedlings, but only when applied at high rates (three applications at $25\,l\,ha^{-1}$).

It is hypothesized that the differences in growth response of broccoli transplants to kelp extract between the Werribee South and Boneo trials relate to the soil type, since other environmental and cultural conditions were identical or similar, i.e. the kelp extract and batch, application method, fertilizer inputs, broccoli cultivar, irrigation regimes, planting time, soil temperatures and day lengths. For example, it may be possible for the higher cation exchange capacity and organic matter in the Sodosol soil at Werribee South (see Table 1) to adsorb or bind active components of the kelp extract, thereby allowing greater opportunity for plant uptake. Alternatively, kelp extracts may have leached through the sandy Podosol soil at Boneo too rapidly to allow efficient uptake by the plant. This is consistent with the observation that higher application rates of kelp extract improved the growth response of broccoli leaves on the Podosol soil. Whatever the mechanism, evidence suggests that application techniques, e.g. application rate, may improve the effectiveness of kelp extracts on sandy Podosol soils. Aldworth and van Staden (1987) noted that foliar application of kelp extracts had little effect on brassicas compared with other crops, due to the waxiness of their leaves. It is possible that the addition of surfactants to kelp extracts and application in a finer spray might improve foliar uptake by brassica crops, as suggested by data from cauliflower (Abetz & Young 1983), thereby reducing the influence of soil factors. By comparison, Pant et al. (2011) found that compost tea fortified with kelp extract stimulated the growth of pak choi on an Oxisol soil, but not on a Mollisol soil. They postulated that the poor drainage of the Mollisol soil suppressed root growth and led to an accumulation of salts following treatment with the compost tea. In the future, the retention, leaching and plant uptake of components of kelp extracts in different soil types warrant further investigation.

In addition to growth effects on the plant, drenching broccoli transplants with kelp extract reduced the early incidence of white blister by 23% at the Werribee South site. White blister control is important because of the potential for significant economic losses in broccoli and other brassica crops (Minchinton et al. 2013). In other vegetable systems, application of kelp extract from *A. nodosum* has reduced disease severity caused by the foliar pathogens *Alternaria cucumerinum*, *Alternaria radicina*, *Didymella applanata* and *Botrytis cinerea* in carrot and cucumber (Jayaraj et al. 2008; Jayaraman et al. 2011). This was associated with increases in the concentration of enzymes, proteins and other compounds involved in defence responses in the plants. Other authors have shown that laminarins contained in various kelp extracts can elicit defence responses in plants (e.g. Klarzynnski et al. 2000; Aziz et al. 2003). It is possible that the reduction in the incidence of white blister caused by kelp extract in the current experiment was due to a similar effect, since Seasol Commercial® concentrate is known to contain laminarins (Seasol International 2013). Several authors have suggested that kelp extracts may form components of integrated management systems for plant pathogens (Wu et al. 1998; Dixon & Walsh 2004; Quilty & Cattle 2011), and may allow growers to reduce fungicide inputs in horticultural systems.

It is highly unlikely that the early growth responses of broccoli in the current trials were due to an NPK fertilizer effect of the kelp extract. This is because the extract contains only low concentrations of nutrients (0.2% N, 0.02% P, 3.7% K, w/v; Seasol International 2013), it was highly diluted, all experiments were conducted under conditions of high nutrition, application of kelp extracts did not affect the nutrient content of soils (unpublished data) and previous authors who studied the identical kelp extract have found that nutrient controls have no effect in stimulating plant growth (Yusuf et al. 2012). Broccoli crops currently rely on high fertilizer inputs (particularly N) at planting to stimulate early transplant growth and high commercial yields (Thompson et al. 2002; Feller & Fink 2005; Yoldas et al. 2008; Bakker et al. 2009). Several studies have shown that kelp extracts can increase nutrient uptake by plants (Crouch et al. 1990; Mancuso et al. 2006; Jannin et al. 2013), which has been attributed to increased root growth, the ability of some components of kelp extracts, e.g. organic acids, to chelate nutrients (Crouch et al. 1990) and enhanced expression of genes that encode for proteins involved in N uptake and assimilation (Jannin et al. 2013). Vernieri et al. (2005), for example, found that the application of a kelp extract into a hydroponic system allowed a 75% reduction in nutrient inputs for salad rocket production. The prospect of kelp extracts with low N inputs stimulating early growth and yield, and potentially allowing reduced or optimized synthetic nutrient inputs, and associated environmental benefits, deserves further examination in the broccoli industry.

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