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The trace element requirements of vegetable and poppies in Tasmania

Ali Salardindi
Tasmanian Institute of
Agricultural Research

Project Number: PT320

PT320

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Tasmanian Institute of
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Project No. PT320

The Trace Element Requirements of Vegetables and Poppies in Tasmania

Project Leader: Dr Ali Salardini

Tasmanian Institute of Agricultural Research

Final Report to

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Final Report of Project Number PT320 to Horticulture Australia Limited

The Trace Element Requirements of Vegetables and Poppies in Tasmania

Dr Ali Salardini and Dr Leigh Sparrow, Tasmanian Institute of Agricultural Research, University of Tasmania

1 Technical Summary

Before 1950s, the deficiency of trace elements, Zn, B, Mo, and Cu had frequently been reported from vegetable growing regions of Tasmania. In contrast, in the recent years, the incidence of these deficiencies has been sporadic. Tasmanian growers are often presented with conflicting advice on trace element requirements and are encouraged to use the forms and formulations of trace elements, the benefits of which have not been adequately demonstrated.

Objectives

This project aimed to develop better trace element fertiliser through the following topical investigations:

1. To determine the need for trace element use on vegetables and poppies.
2. To compare the efficiency of foliar and soil applied trace elements in mineral, chelated or lignated forms.
3. To examine the usefulness of soil and plant analysis as a diagnostic technique for predicting the trace element requirements of vegetables and field poppies.
4. To provide vegetable and poppy growers with accurate trace element fertiliser recommendations based on soil and plant analysis.

Methodology. During the three years life of the study, we completed 12 foliar and 7 soil applied trace element experiments on the main processing vegetable crops- potatoes (10 sites), cauliflower, broccoli, green peas, green beans, carrots, sweet corn and field poppies. The sites with the lowest content of one or more of the Zn, Cu, B, Mo and Mn were selected after consulting more than 1000 commercial soil analytical results and repeating the sampling and analysis of 60 with the lowest trace element concentrations.

Two or all of the commonly used sources of trace element fertilisers, mineral, chelate and lignate were compared in most experiments. We applied trace elements as foliar sprays, in bands together with NPK fertiliser and in preplant broadcasting or combination of these methods. Total and marketable yields, industry quality criteria and soil and plant tissue composition were determined and discussed in all experiments.

Yield response. Because of routine application of trace elements in the past two or three decades, most long-established vegetable farms are sufficiently supplied with trace elements. Although we selected sites with the lowest trace element content that we could find, in 171 combinations of treatments resulted from variations in crops, method and rates of application and trace elements, only 9 positive or negative yield or quality responses were observed.

Soil analysis. This study showed that, when the interpretation criteria presented in the recent Australian "Soil Analysis- an Interpretation Manual" (Peverill *et al.* 1999.) were used, soil analysis gave reasonable predictions of soil trace element status. The predictions were more accurate where crop species and soil type were taken into account. We tabulated the interpretation guides for soil Zn, Cu and B status that could be used more appropriately on vegetable crops in northern Tasmania. We strongly believe that the critical soil trace element concentrations employed by the local fertiliser advisers are many folds greater than the correct values.

Plant analysis. In nearly all experiments, plant analysis results when interpreted using the guidelines reported in the "Plant analysis-an Interpretation Manual (Reuter and Robinson 1997), correctly predicted the response of crop to trace elements. We did not attempt to tabulate the critical concentration of trace element in plant tissues, because these concentrations may vary with the plant species, cultivars and parts, stage of growth and the interaction of other nutrients. We recommend that the plant analysis manual to be consulted for plant analysis interpretation.

Source and methods of application. All sources, when applied as foliar spray, were readily absorbed and translocated to other tissues, such as seeds in poppies. When these were applied to soil, the change in tissue concentration was not as pronounced as in the case of foliar use. Band placed method, even at lower rate was more effective than broadcast application. The efficiency of sources applied at similar rates were in order of Chelate<Lignate<Mineral. At commercially recommended rates, they were similarly effective and costing the same.

Trace element recommendation. We believe that the need for trace elements application to vegetables in Tasmania is grossly over-estimated by most local and visiting farm consultants.

Although it is correct that certain crops require more of some trace elements, we do not believe that trace elements routinely be applied to these crops unless soil analysis identified a need. This suggestion prevents the probable imbalance of these nutrients in soil, which may cause toxicity of one or deficiency of other trace elements.

In Tasmania, vegetable crops are receiving foliar sprays of trace elements only as insurance, and not to correct known deficiencies. Much of visual improvements are due to the effects of major elements mainly N in the commercial mixes. Although the reduction of yield or damage to soil health is not expected by the use of most commercial foliar products, they are more likely to be costly and useless under our conditions, unless are used to correct a known deficiency.

Technology transfer. The outcomes of the study were presented to vegetable, poppy and associated industries such as fertiliser companies, agricultural consultants, analytical laboratories, seed and seedling companies. The outcomes were decimated in six technical seminars, six field days, a number of extension talks to farmers and two popular publications. We recommend establishing a new series of activities to extend the outcomes of the project further.

2 Media Summary

A Horticulture Australia funded project was conducted in 1993-96 by the Tasmanian Institute of Agricultural Research and Department of Primary Industry, Water and Energy, Tasmania to develop better trace element fertiliser use strategies for vegetable crops and field poppies in Tasmania. We acknowledge the financial support of Tasmanian Farmers and Grazier Association, Simplot, McCain, Tasmanian Alkaloids, GlaxoWelcome, Pivot Agriculture, Impact Fertilizers and Serve-Ag.

In 19 experiments on potatoes (10 sites), cauliflower, broccoli, green peas, green beans, carrots, sweet corn and field we studied the use of different forms of Zn, Cu, B and Mo fertilisers.

Because of routine application of trace elements in the past two or three decades, most long-established vegetable farms were sufficiently supplied with trace elements. Although we selected sites with the lowest trace element content only in three experiments, we found a yield or quality responses to trace element fertilisers. All forms of trace element fertilisers (mineral or complex), at commercially recommended rates, were similar in being taken up by vegetables and were costing the same. We believe that the need for trace elements application to vegetables in Tasmania is grossly over-estimated by most local and visiting farm consultants.

Soil analysis gave accurate predictions of soil trace element needs, when the recent Australian publication "Soil Analysis- an Interpretation Manual" (Peverill *et al.* 1999.) was used for the interpretation. The predictions were more accurate where crop species and soil type were taken into account. We tabulated the interpretation guides for soil Zn, Cu and B status that could be used more appropriately on vegetable crops in northern Tasmania.

Plant analysis also correctly predicted the response of crop to trace elements when the guidelines reported in the "Plant analysis-an Interpretation Manual (Reuter and Robinson 1997) were used.

The outcomes of the study were presented to vegetable and poppy growers and fertiliser suppliers, agricultural consultants, analytical laboratories, seed and seedling companies in technical seminars, field days, farmers groups and popular publications

We recommend that trace elements should not be routinely or as an insurance policy applied to vegetable crops, unless a trace element deficiency is identified by soil and plant analysis. This will prevent the loss of resources and occurrence of probable imbalance of these nutrients in soil, which may cause toxicity of one or deficiency of other trace elements.

To achieve a full use of the outcomes of the project, we recommend conducting a new series of extension activities in the form of workshops, field days, discussion groups for farmers and farm advisers and popular publications. Additionally, the information may be prepared as pocket size manuals and Internet files to be added to the relevant sites.

3 Publication schedule

The outcomes of the study have already been presented to vegetable, poppy and associated industries such as fertiliser companies, agricultural consultants, analytical laboratories, seed and seedling companies. The outcomes were decimated in six technical seminars, six field days, a number of extension talks to farmers and two popular publications.

As more scientific publications and extension activities are required to extend the outcomes of the project further, we recommend establishing a new projct to fufill these objectives..

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Dr Ali Salardini and Dr Leigh Sparrow
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4 Project overview - objectives and information common to all studies

4.1 Introduction

Plants synthesise their food from simple substances taken out of their environment, the air and the soil. They need several nutrient elements in sufficient amounts and in proper balance to build their body tissues and to synthesise a group of enzymes for the functioning of their tissues. At least 20 nutrient elements are known to be essential for the normal functioning of green plants. These elements are divided into two arbitrary groups: the major elements and trace elements. Those vital elements that are required only in very small quantities by plants have been identified as microelements, micronutrients or trace elements. For higher plants, copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), boron (B), molybdenum (Mo), and chlorine (Cl) are generally recognised as essential trace elements and cobalt (Co) essential only for leguminous and some other crops. The total weight of trace elements removed by an average vegetable crop is less than 2 kg/ha, nearly 150 fold less than that for the major elements.

Some soils contain low levels of certain trace elements because of the nature of their parent materials and/or climatic factors particularly rainfall (leaching) and temperature (Cox and Kamprath, 1972). Most ferrosols, the major soil used in vegetable production in Tasmania, especially the high rainfall zones, are naturally low in B, Mo, Zn and Cu (Srivastava and Gupta 1996).

A sub-optimal or excess supply of trace elements adversely affects yield and quality of crops. An accurate and early diagnosis of trace element problems is very important to adopt timely corrective measures. Most acute deficiencies or toxicities of trace elements are manifested by some morphological and visual symptoms on plants that can be used for diagnosis of the problem. However, more reliable diagnostic methods, involving soil and/or plant analyses are used universally to identify the soil and plant trace element status.

The diagnosis of soil trace element disorders is based on the use of suitable extractants that could dissolve a quantity of trace elements closely correlated to plant uptake. For a test to be acceptable for prediction of soil trace element status and to be used for recommendation of fertiliser, it must be calibrated with the yield and/or quality of crops. The more common extractants used for soil trace element diagnosis have been calibrated for many crops and the critical concentrations are reported in literature for different soil types and for the crops.

Most boron soil tests are the modifications of the hot water extraction method of Berger and Truog (1939) of which hot 0.01M $CaCl_2$ of Aitken *et al.* (1987) is routinely used in Australia. The more common test for the metallic trace elements is based on the use of extractants containing a chelating agent. In Australia, the DTPA test of Lindsay and Norvell (1978) which employs diethylenetriaminepentaacetic acid (DTPA) is well accepted. Some laboratories however use the ammonium bicarbonate/EDTA procedure of Trierweiler and Lindsay (1969) with modifications suggested by Best *et al.* (1985).

4.2 The problem

The deficiency of four trace elements, B, Mo, Zn and Cu had frequently been reported on crops including vegetable crops before 1950s. Deficiencies of Mo have been reported in the sandy soils of Cressy (Fricke 1944) in ferrosols of north western (Fricke 1945) and other regions of Tasmania (Paton 1956). Boron and Mo deficiency in *Brassica* forage crops (Lamp 1964), Mo deficiency in green peas (Wade 1952) and Zn deficiency in beans had frequently been reported. Laughlin (1980) studied B deficiency in poppies and showed a yield response to B application.

In contrast, in recent years, the incidence of trace element deficiencies has been sporadic and mostly limited to the deficiency of B or Mo in *Brassica* crops. The scarcity of trace element deficiency may have been the result of a common practice that fertiliser containing trace elements has been frequently used in vegetable production as an insurance against probable deficiencies. The routine soil test for the recommendation of fertiliser in vegetable growing areas of Tasmania does not normally include trace element assessments. Even when soil trace element tests are conducted, the critical trace element concentration, below which the application of trace elements is recommended, are set to the levels higher than those reported in the literature in other countries.

The infrequent soil trace element tests and elevated critical concentrations have encouraged vegetable growers to apply trace elements routinely at least once during 3-5 year rotations, which normally include onions, potatoes and *Brassica* crops. This has enhanced the development and promotion of various commercial forms of micronutrient fertilisers widely recommended to farmers.

Since metallic trace elements are less mobile they are accumulated in the topsoil, while B and Mo may not remain in the root zone even after only a year of their application. With the application of large amounts of Zn and Cu to the vegetable soils in the past two to three decades it is possible that the deficiency of these elements is less likely. However, the status of soil B and Mo may not be clearly anticipated.

4.3 Objectives

Although in excess of $1,000,000 is annually spent on trace element fertilisers for vegetable crops in Tasmania (estimated from the sale values of major fertiliser suppliers), there has been no firm evidence that this expenditure was justified or conversely that higher inputs of trace elements were needed. Tasmania growers and probably growers in other states, are often presented with conflicting advice on trace element requirements and are encouraged to use forms and formulations of trace elements, the benefits of which have not been adequately demonstrated. This project seeks to develop better trace element fertiliser strategies to maximise production and provide vegetable growers with accurate recommendations through the following topical investigations:

1. To determine the need for Zn, Cu, B, Mo and Mn in potatoes, *Brassica* crops, carrots, peas, beans and field poppies.
5. To compare the efficiency of foliar and soil applied trace elements in mineral, chelated or lignated forms.
6. To examine the usefulness of plant analysis as a diagnostic technique for predicting the trace element requirements of vegetables and field poppies.
7. To provide vegetable and poppy growers with accurate trace element fertiliser recommendations based on soil and plant analysis.

4.4 Materials and Methods

4.4.1 Soils and crops

In 20 experiments on 8 crops on soils of northern Tasmania, the effects of soil, foliar or both soil and foliar application of one or a range of trace elements B, Cu, Mn, Mo and Zn supplied from different sources were studied. The soil types were predominantly ferrosol, but some vertosol and sandy demosols were also included. The crops investigated were potatoes, carrots, green beans, green peas, field poppies, cauliflower, Brussels sprouts, and broccoli.

4.4.2 Site Selection

As there had been no report of visual symptoms of trace element deficiency, the only possibility of finding sites with suitable available trace element content for our experiments was by random soil analysis of the paddocks. This procedure was very costly and did not guarantee reaching the suitable sites. With the help of the Tasmanian Farmers and Graziers Association (TFGA) and the commercial soil and plant analysis service providers, many vegetable growers authorised us to access the results of their soil and plant analyses. Only a small proportion of soils analysed for fertiliser recommendation included trace element tests. Most of soils from the vegetable growing region of northern Tasmania were shown relatively high in most trace elements. Probably this was the result of application of trace elements following the return of previous soil results. Using the United States and European soil critical trace element concentrations to identify trace element deficient soils, we found only 60 paddock amongst those 1000 analysed to be deficient in any of trace elements. The soils from these sites were re-analysed by the DPIWE Analytical Laboratories, using the Australian standard methods (Rayment and Higginson 1992) However, some local consultants were using much elevated critical concentrations that would have grouped many of those soils to be deficient in trace elements. To determine whether there was any needs for trace element use under those conditions, we conducted our experiments in the paddocks with the lowest soil test value for one or more of the trace elements that we could find. Those paddocks, however, would have been identified as deficient by the consultants and would have received trace element recommendations.

4.4.3 Methods, source and rate of application of trace elements

Trace element and other fertilisers were applied using three soil and one foliar application method. Soil application methods included incorporation, band-placement and top-dressed. In the incorporation method, before planting, solid fertilisers were broadcast and liquid fertilisers were sprayed on the soil surface before they were incorporated into the top 10-15 cm soil, using a disk plough or rotary hoe. In band placing, at the time of planting, trace element and major fertilisers were mixed together and placed in two bands 10-15 cm deep and 5 cm to each side of plant rows. Top-dressing was performed after crop establishment and usually at mid-growth stage. In top-dressing, solid trace element fertilisers were broadcast onto the plots immediately before irrigation being applied. In the foliar method, solid and liquid trace element fertilisers were dissolved or diluted with water and a surfactant or wetting agent was added before they were brought to an equivalent volume of 250-400 L/ha and sprayed on the crop using a standard knapsack spray unit.

The rate of applied fertilisers varied with the elements and method of application. However, when the effect of rate of any propriety fertiliser was studied a rate close to the producer recommended rates was included in the treatments. In the case of generic material, the rates applied contained one or two rates conventionally used.

Metallic trace elements Zn, Cu and Mn were applied from three sources: mineral, chelates and lignosulfonate. Boron and Mo were used as either mineral or lignosulfonate. We did not examine the chemical nature of any of the sources and assumed that they were in the forms, as the labels would indicate. The specifications of some of the fertilisers used in the experiments are shown in Table 1.

4.4.4 Nature of treatments

In many experiments, the need for each trace element was studied especially when foliar applications were tested. In those experiments the crop receiving a balanced mixture composed of all trace elements *(Complete or Full)* was compared with those receiving no trace element (*Control*) and those on mixtures from which one of the various micronutrients were deleted *(Deficient)*. Since some propriety foliar blends employed contained nitrogen to enhance the uptake of trace elements, the effect of addition and deletion of N was also tested. In another series of experiments, the effects of source and rate of trace element application were studied. In those experiments, usually only one trace element was investigated. When application methods were compared, at an appropriate stage of growth the plots, which had or had not received the basal trace elements at planting, were split and foliar treatment was applied to the subplot, so that basal, foliar and combined treatments could be compared.

Table 1. Sources of trace element fertilisers used in experiments

Form	Composition	Element	Trade name	Supplier	Elemental rate	
					Foliar	Basal
		(%)			(g/ha)	(kg/ha)
B lignate	Lignosulfonate	0.75 B	B lignate	Thrive-Ag	100-500	0.1-0.5
Borax		11.3 B	Borax	Borax Cons	-	1-4
Solubor		20.5 B	Solubor	Borax Cons	500-1000	1-2
Mo lignate	Lignosulfonate	13 Mo	Mo lignate	Thrive-Ag	35-100	0.01-0.05
Molybdate	$Na_2MoO_4.2H_2O$	39 Mo	Generic	-	50-100	0.1-0.4
Cu lignate	Lignosulfonate	5.5 Cu	Cu lignate	Thrive-Ag	75-150	0.5-1
Cu chelate	Cu-EDTA	6 Cu	Supa Copper	Agrichem	0.1-0.2	1-2
Cu sulfate	$CuSO_4$	6.7 Cu	Coppersol	Pivot	300-500	1-2
Cu sulfate	$CuSO_4.H_2O$	22.4 Cu	Generic	-	100-250	5-10
Mn chelate	Mn-EDTA	9 Mn	Supa Manganese	Agrichem	250-500	500-1000
Zn sulfate	$ZnSO_4.7H_2O$	6.25	Zincsol, L	Pivot	0.5-1	1-2
Zn chelate	Zn-EDTA	6.25	Supa Zinc, L	Agrichem	0.1-0.5	0.5-2
Zn lignate	Lignosulfonate	6.8 Zn	Zn lignate	Thrive-Ag	0.01-0.05	0.1-0.5
Trace supplement	B, Zn, Cu and Mo	0.7 B, 0.6 Zn, 0.57 Cu 0.02 Mo	Generic	-		5-10 kg of mixture/ ha
Complete liquid	NPK + Trace	9-4-6 + trace	Top Foliar	Pivot	-	-

4.4.5 Soil and plant analysis

Before any experiments were established, soil cores of 0-150 and 150-300 mm were taken from the experimental site and bulked to give one composite sample for each depth. Samples were analysed by the commercial DPIWE Laboratories, following the Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson, 1992). Electrical conductivity and pH (pH_w) in a 1:5 soil/water suspension; bicarbonate extractable P and K (Colwell *et al.*, 1963), using 1 part soil in 100 parts 0.5 M sodium bicarbonate solution at pH 8.5. The elements Mn, Cu, Zn, Mg and Ca were extracted with DTPA (diethylenetriaminepentaacetic acid) at a soil:solution ratio of 1:2 at pH 7.3. Boron was extracted by hot water or hot $CaCl_2$ and results were reported as hot water soluble B (HWSB). However, some samples were also tested by other commercial laboratories such as Thrive-Ag Consultants Ltd. (Yarraville Victoria), Pivot Ltd. or Incitec Ltd.

For plant tissue sampling, our selection of time of sampling and the tissue sampled was generally guided by the Plant Analysis Manual (Reuter and Robinson 1986) with some modification as needed. In most experiments, the petioles of the youngest fully expanded leaves (PYFEL) were sampled. However for broccoli in two experiments whole leaf (WYFEL) was sampled. In tissue sampling after foliar application, at least two weeks period was allowed, to provide sufficient time after foliar or top-dressed treatments, for the new leaves to emerge and become fully expanded. In some experiments, before foliar treatment, tissue samples were also taken from each plot or the site.

Plant tissue samples were dried at 70 °C, ground and sub-samples were digested in a HNO_3 - $HClO_4$ mixture and analysed for a range of nutrients. Either a graphite furnace atomic absorption spectrophotometer (AAS) or an inductively coupled plasma emission spectrophotometer (ICP) used to determine the concentrations of nutrients in the both soil extracts and the plant digests.

4.4.6 Criteria determined

The criteria determined varied with the crop. For potato the total and processing yields of tubers, the distribution of tubers into size grades of <100, 100-280, 280-450, > 450g and misshapen were determined. Subsamples from the 280-450 g grade were taken for quality assessment, which consisted of determination of specific gravity (SG), bruising index and crisp colour.

The criteria determined for carrots were total and marketable yields, size distribution of roots into size grades of >40, 40-120, 120-240, >240 g and misshapen. Subsamples of the marketable roots were tested for quality assessment such as cracking intensity, hollow root and discoloration.

For sweet corn the total and marketable primary and secondary cob yield and the cob quality criteria such as weight, diameter, length, cob: husk ratio, tip-fill, colour and seed row pattern were recorded.

The criteria determined on broccoli were total and marketable yields, head weight and the head quality factors including colour, hollow stem, starring (yellow open flower), browning, compactness and leaves in the head.

For cauliflower the total and marketable yields, curd (head) weight and curd quality criteria: shape, evenness, colour, firmness, riciness (powdery appearance), hollow stem and presence of bract (small leaves) were recorded.

For green peas and green beans the total and marketable pod yield, pod:straw ratio, and seed maturity index (MI) were recorded.

5 Details of Foliar trace element experiments

Some growers in the vegetable growing area of northern Tasmania use foliar fertilisers containing trace elements or a combination of both major and trace elements, hoping to improve the yield and/or quality of different vegetable and other crops. This practice is supported by the positive responses observed in other states on different soil types, many of which are very poor in fertility (Robson and Gilkes 1980) Although some colour or vigour improvements had been shown in demonstrational experiments by some of the suppliers, there was no evidence available to conclude that any significant yield or quality improvement had been achieved. Our objective in the following investigations was to identify the usefulness of application of a series of foliar trace element fertilisers for vegetable and poppy crops under our soil and climatic conditions.

5.1 Poppy experiment (Zn, Cu, B, Mo)

5.1.1 Methods

This foliar experiment (TE-2) was established within a commercial poppy crop at Forthside Vegetable Research Station (FVRS) 5 km west of Devonport (41 ° 12' S, 146 ° 22'E) into a deep clay loam ferrosol. The paddock had received 5 t/ha dolomite (26% Ca and 8.5% Mg) and 375 kg/ha a commercial grade fertiliser 14-16-11 (N-P-K) prior to sowing of poppy in August 1993. Soil and plant samples were taken in late November, immediately before application of foliar treatments, when plants were at hook stage. Poppy crop usually receives top-dressing and foliar fertilisers at this stage of growth. The soil analysis results for 0-200 mm depth were pH $_{H2O}$, 6.1, Colwell P and K, 78 and 150 mg/kg, DTPA extractable trace elements (in mg/kg) Fe 42, Zn 1.05, Cu, 2.43, and Mn 68.5.

Foliar treatments consisted of applications of 8 different fertiliser solutions (Table 2) at rate recommended by the supplier at hook stage and capsule formation on 24 November 1993 and 1 January 1994 respectively.

Table 2. Foliar treatments applied in poppy experiment (TE-2)

Treatment		Description
No	Name or code	
1	Control	No foliar fertiliser applications
2	Full traces with urea [FT]	12.5 L Lignate-Trace Elements and 1 kg/ha urea providing (in g/ha) 225 Cu, 375 Zn, 37.5 Mo, 8.78 B and 460 N
3	Urea [U]	Urea alone
4	[FT} - Zn	As 2, but without Zn
5	[FT] - Cu	As 2, but without Cu
6	[FT] - B	As 2, but without B
7	[FT] - Mo	As 2, but without Mo
8	[FT] -Urea	As 2, but without Urea

Whole leaf (YFEL) samples were taken on 1 January immediately before the second foliar spray was applied. Samples were washed with deionised water, dried, ground and analysed for both major and trace elements. The crop was harvested on 7 February 1994 and capsule and seed yields were recorded. All capsules were picked from 2 m^2 of each plot, dried at 60 °C and the weight was recorded (total). The capsules were then crushed, seeds and the remaining dried materials (straw) were separated and weighed. Samples of seed were also taken and analysed for trace element content.

5.1.2 Results

The yield of straw and seed was not affected by application of urea alone or together with trace elements. When urea, Zn, or Mo was omitted from the spray solution, the yields of both capsule and seed were significantly lower (*P*=0.03). When copper was left out of the solution there was no changes in yield (Figure 1). This indicated that Cu might have been the cause of lower yield in other treatments, and addition of urea, Zn and especially Mo had reduced the damage caused by copper.

There is no published information on the levels of soil and plant concentration of trace elements relating to poppy YFEL that can be used for diagnostic purposes. The concentrations of Cu and Zn in YFEL at hook stage, prior to foliar treatment were 8 and 27 mg/kg respectively, and are considered marginal.

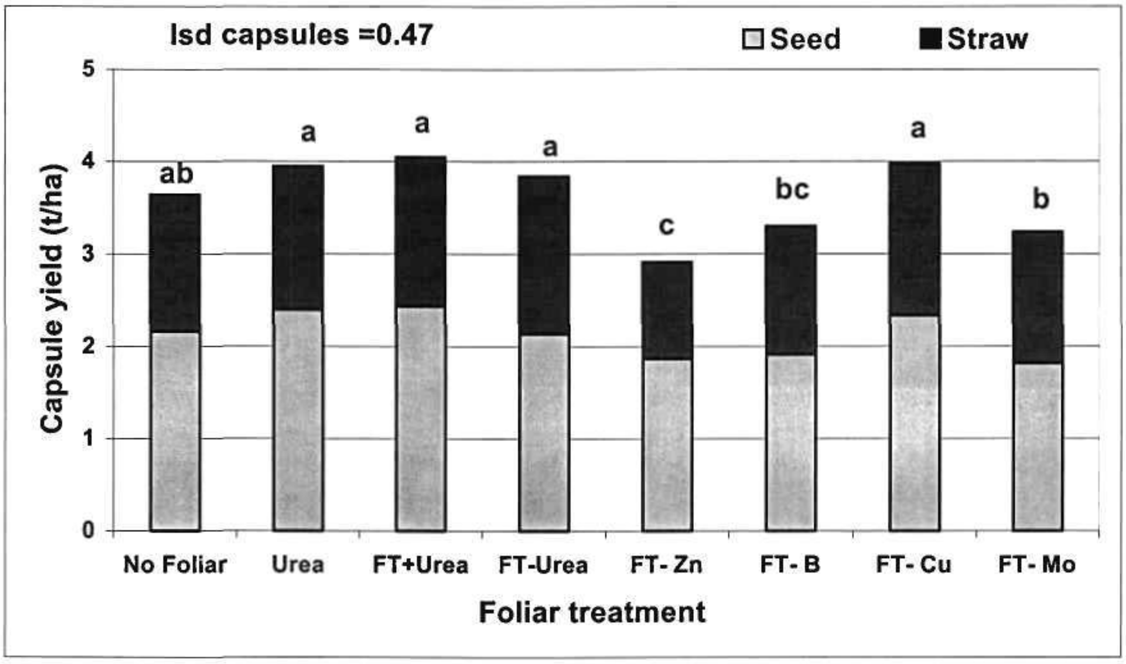

Figure 1. Yield of seed (grey segment), straw (black segment) and capsule the sum of them (column) of poppy as influenced by foliar lignate trace element applications. The columns with the same letter are not significantly different by Duncan Multiple range Test ($p<0.05$)

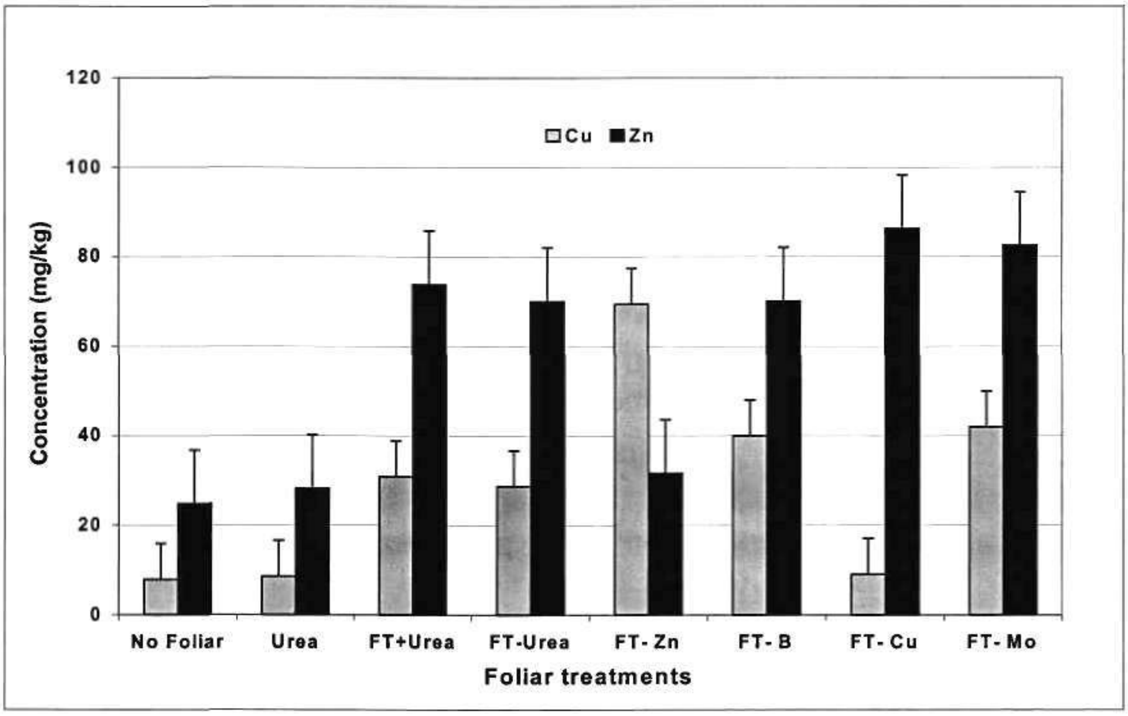

Figure 2. Effect of foliar application of different trace element treatments on Cu and Zn concentrations in the YFEL of poppy plants at hook stage, 37 days after the foliar application of trace elements

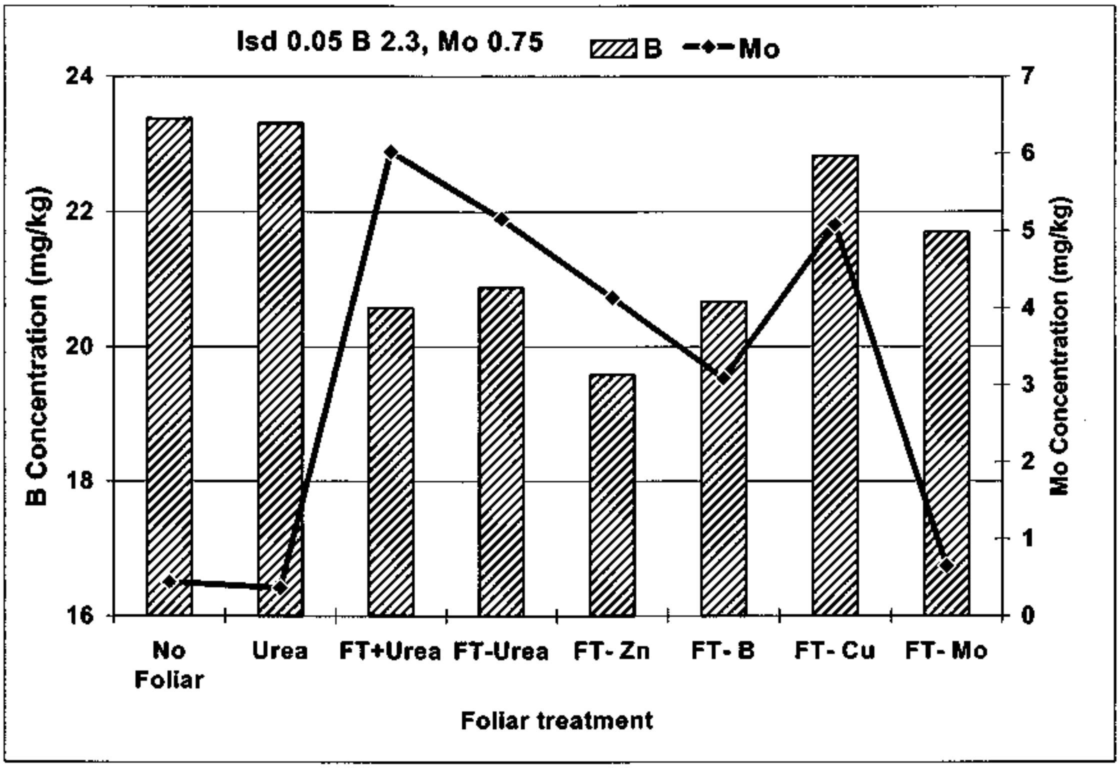

Figure 3. Concentration of B and Mo in whole YFEL 37 days after the foliar application of trace elements

The results of YFEL analysis (Figure 2) showed that when either B, Mo or especially Zn was not present in the Cu containing foliar solution, the concentration of Cu increased by 3-10 fold the normal concentrations (*P*=<0.001), which may have been a cause of yield reduction. Absence of Zn caused the Cu concentration to rise more significantly.

Boron and Mo also showed an interaction (Figure 3). In the absence of Mo, the concentration of B increased (*P*<0.001), but unlike the Zn-Cu interaction, the absence of B reduced the concentration of Mo in YFEL.

The results of seed analysis showed that foliar nutrients have been transported to the seed, and there was significant increase (*P*<0.001) in the concentration of Zn, Cu and Mo when these elements were present in the foliar fertiliser mix. The Zn-Cu interaction, similar to that in the YFEL tissues, was also observed for the seed concentrations of these elements. In the presence of Cu and with application of Zn, the concentration of Zn remained at 48±2 mg/kg seed dry matter, but when Cu was not present application of Zn increased Zn concentration in the seed to 54 mg/kg.

5.1.3 Conclusions to the poppy foliar study

The application of foliar trace elements increased the uptake of these nutrients into YFEL tissue and the seed when applied at hook stage. This indicated that trace elements applied to the foliage of poppy could be readily absorbed and translocated within the plant and influence the composition of seed. Had plant been deficient in any of trace elements, their application could have resulted in a plants growth improvement.

The remedial effect of urea in this experiment could not be attributed to its effect on plant trace element composition, since it did not change the concentration of any of the elements studied (Figures 2 and 3). Incidence of Cu toxicity because of the use of only 100 g Cu/ha, shows the hazard of unnecessary use of foliar trace element fertilisers. In addition, the corrective effect of Zn on excess Cu may indicate that application of Zn may be able to be used to reduce the toxic effect of Cu, where soils are high in Cu. The soil DTPA extractable Zn results (DTPA-Zn=1mg/kg), based on the scale commonly used in the USA predicted no response to Zn application for other crops, while locally a soil DTPA-Zn of <2 mg/kg is considered to be deficient and Zn fertiliser is recommended. The result of this experiment confirms that, at least for the poppies, the critical Zn concentration used in Tasmania is too high.

5.2 Sweet corn

5.2.1 Methods

This foliar experiment (TE-5) was established within a commercial sweet corn crop at Forthside Vegetable Research Station (see 2.1 for station information). The paddock had received a full range of trace elements prior to an onion crop two years earlier, and 500 kg/ha of a commercial grade fertiliser 14-16-11 (N-P-K) band-placed at planting of this experiment, on 20 November 1993. Sweet corn hybrid Terrific was sown on 20 November 1993 and harvested on 8 March 1994. The number and fresh weight of marketable and unmarketable primary and secondary cobs, weight of husk and the quality of cob including husk length, cob length, cob diameter, tip fill, cob colour, and seed rowing grades were recorded. Soil samples were taken before planting. Plant samples were taken 3 weeks after application of second foliar treatments, on 4 February 1994, when plants were at full tasselling stage and were analysed by two commercial laboratories. Leaf blades opposite and below the primary cob were taken, dried, ground and analysed for the major and trace elements. The soil analysis results are given in Table 3.

Fertiliser treatments consisted of two foliar applications of lignosulfonate liquid fertilisers on 24 November 93 and 11 January 1994. The treatments included Control (no foliar fertiliser), FT-Lignate, FT-Mineral, FT-Zn, FT-B, FT-Cu and FT-Mo. The treatment codes and trace element concentrations are as reported in Table 2 for the poppy experiment, except that urea was not included in the foliar solutions. FT-Mineral had identical composition to that of FT-Lignate, but trace elements were applied from generic mineral sources (see Table 1).

5.2.2 Results

The results of soil analysis by Thrive-Ag Ltd. indicated the paddock to be very high in Mn and Cu, low in Zn, very deficient in Mo and marginal in B. We interpreted the results of tests conducted by DPIWE laboratory (the laboratory did not provide interpretation) to be adequate in all trace elements, except Zn that was considered to be deficient (Table 3).

As predicted from the DPIWE laboratory soil analysis results, there was no significant response in either yield to the omission of Cu, Mn, B or Mo from the foliar solutions. Although the soil Zn content was slightly below the adequate level of 1 mg/kg, and we assumed the possibility of reduction in yield or changes in the quality characteristics in the treatments without Zn (control and FT-Zn), there was no response to the omission of Zn from the fertiliser solution. Plant tissue analysis showed only small changes in the trace element content of leaves with addition or omission of the relevant or other elements. Zinc concentration of leaves were high (50 ± 10 mg/kg)) in all treatments. However, tissue Cu content was slightly, but significantly (P=0.05) reduced when Cu was omitted or Zn was added to the solution.

The quality characteristics such as tip-fill, colour, weight, diameter, length and kernel rows of the primary or secondary cobs were not affected by any of the treatments applied.

Table 3. Soil analysis results of topsoil (200 mm) of sweet corn experiment (TE-05)

Laboratory[A]	pH	Org. C	P	K	B	Zn	Cu	Mn
	(H_2O)	%	(mg/kg)					
DPIWE,	6.0	4.4	96	190	2.06	0.81	2.59	129
Tasmania	Ad	Hi	Marg	Marg	Ad	Lo	Ad	Hi
Thrive-Ag	5.5	4.3	10	208	1.36	2.30	10.29	386
	V Acid	Hi	Marg	Ad	Marg	Lo	V Hi	V Hi

[A] Methods of soil analysis are described in section 1.4.5. Abbreviations: Ad = Adequate, Hi = High, Marg = Marginal, Lo = Low, V = Very

5.2.3 Conclusions to the Sweet corn foliar study

There was a significant difference in the methods of analyses employed by Thrive-Ag as compared with the Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson, 1992). It appears that the soil threshold of deficiency adapted by the consultants for the recommendation of trace elements to sweet corn in northern Tasmania, is much higher than those adapted by the independent organisations.

The plant tissue test showed that the control plants were adequate in Zn, Cu and B and predicted the response to the application of these elements more accurately than soil analysis.

5.3 Broccoli

5.3.1 Methods

This foliar experiment (TE-14) was conducted in a commercial broccoli crop at Forthside Vegetable Research Station (FVRS) 5 km west of Devonport into a deep clay loam ferrosol. In the previous experiments, the effects of omission of a single element from a fertiliser solution containing all elements were investigated. That is, all trace elements were present except one. In the current experiment the objective was to investigate the effect of application of a single trace element in the, different rates and sources of this element was chosen to be investigated. The crop received 500 kg DAP (20-18-0, N-P-K) fortified with 0.7% B and 0.02% Mo band-placed at planting on 23 August, two top-dressings of ammonium nitrate at 20 kg N/ha each on 29 September and 3 November and a foliar NPK fertiliser (7-7-9, N-P-K) on 1 September 1994. The crop was harvested sequentially at 5 different dates (25 November to 7 December 1994) when heads reached marketable sizes. The yield and quality characteristics such as hollow stem, starring, colour, compactness, browning and presence of leaves were assessed for sub-samples of harvested heads. Each quality characteristic was ranked to a scale of 1 to 5 (5 was the best) and the overall quality ranking was calculated as the mean of individual quality characteristics.

Soil samples were taken from the site in late July 1994, before application of basal fertilisers and were analysed by Thrive-Ag and DPIWE Laboratories for major and trace elements, results of which are shown in Table 4. Plant samples, YFEL (leaf and stalk, fifth leaf from top of plant) were taken when plants were at buttoning stage, dried at 60 °C, ground and analysed for Cu and Zn using atomic absorption spectroscopy.

Table 4. Some characteristics of soil (0-200 mm) used for the broccoli experiment

Lab.	**pH**	**Org. C**	**P**	**K**	**B**	**Mo**	**Zn**	**Cu**	**Mn**
	(H_2O)	**%**	**(mg/kg)**						
Thrive -Ag	5.5 V Acidic	5.8 Hi	21.3 Marg	301 Ad	1.34 Marg	0.24 V Def	3.7 Marg	8.7 V Hi	201 V Hi
DPIWE	6.5 Ad	3.9 Ad	98 Marg	143 Low	1.30 Ad	-	0.65 Marg	3.0 Hi.	65 Hi

For abbreviation see Table 3

Table 5. The rate and sources of Zn fertilisers

Treatment	**Trade name**	**Zn applied kg/ha**	**Fertiliser rate L/ha**
Control	No Zn	0	0
Zn sulfate	Zincsol	1 and 2	6.25
Zn chelate	Supazinc	0.5 and 1	6.25
Zn lignate	Thrive-Ag zinc	0.5 and 1	7.00

The foliar treatments consisted of a control (no Zn), two rates of Zn (normal and high) applied from three different sources with four replicates. The sources of zinc were zinc sulfate, zinc chelate, and zinc lignate as shown in Table 5 (see also Section 1.4.3 and Table 1 for details of sources of fertilisers).

5.3.2 Results

There were inconsistencies between the results returned from the two laboratories. However these inconsistencies did not influence the decision to conduct the experiment, as one of objectives of this work was to examine the validity of some soil analysis interpretations leading to recommendation of trace element use for vegetable crops. Only a soil DTPA extractable Zn concentration of <1 mg/kg is considered deficient for many crops (Brennan *et al.* 1993).

This crop produced a marketable yield of 16 t/ha, about 30% higher than the region average. Application of Zn from any sources did not influence marketable yield or the overall quality characteristics determined for the sum of five harvesting dates, but the effects were different when the date of each harvest was also considered. The yield of first and second harvest was doubled when 0.5 kg Zn/ha was applied in chelate form. At 1 kg Zn/ha in chelate form, the increase was 30%. At the lower rate of Zn, the lignate and sulfate sources did not have any effect, but at the higher rate the yield increase over the control was 25 and 30% for lignate and sulfate respectively (Figure 4).

Some of the quality characteristics including starring, hollow heart, colour and presence of bracts in the head were also improved by Zn application. The overall quality ranking of the heads from the first two harvests was influenced by Zn application similar to that of the yields. Figure 5 shows the overall quality and colour ranking, the latter as an example of individual quality characteristics, at first harvest. The figure indicated that there was an improvement in the quality of heads with application of the lower rate of Zn chelate and the higher rate of Zn from the other sources.

Application of Zn did not influence the concentration of Zn in the YFEL (24.7 ± 1.8), but Cu concentration, contrary to the antagonistic effects between Zn and Cu observed in other crops, increased Cu concentrations (3.9 ± 0.2) in the YFEL. The increase, although small (10%), was highly significant (*P*=0.01) for the lower rate of Zn chelate and higher rate of Zn from other sources.

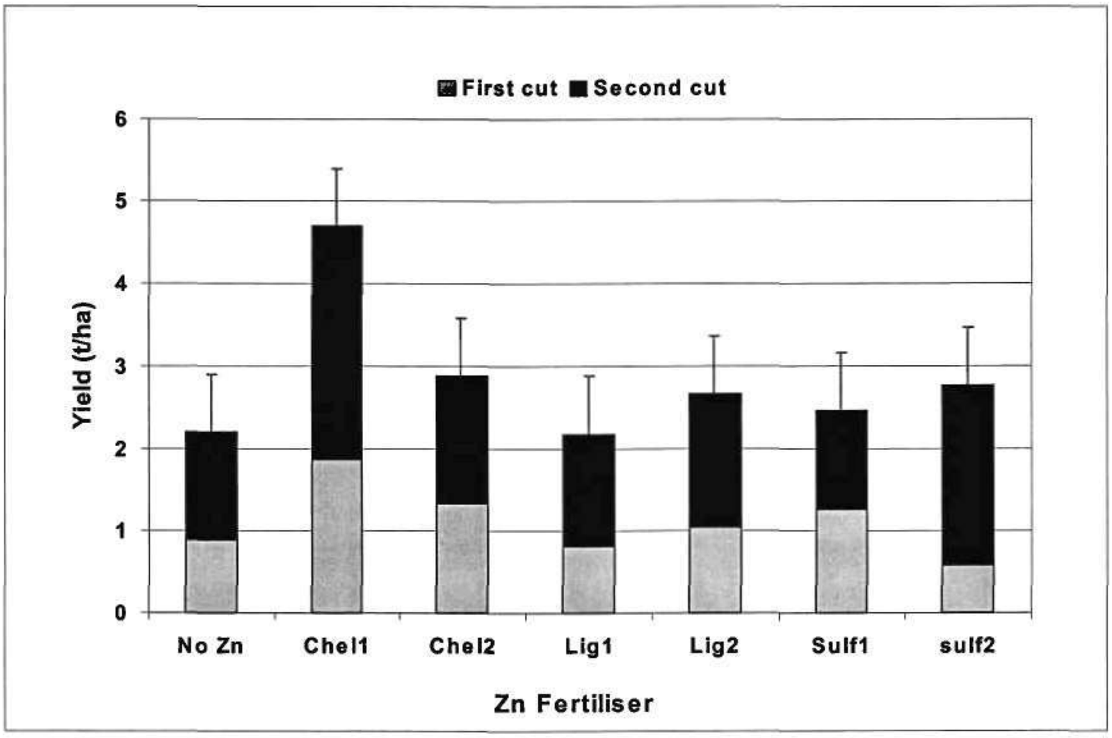

Figure 4. Yield response of broccoli at first harvest (grey segment), second harvest (black segment) and their sum (whole column) to foliar Zn fertilisers. Vertical lines are lsd $_{0.05}$ for the total yield.

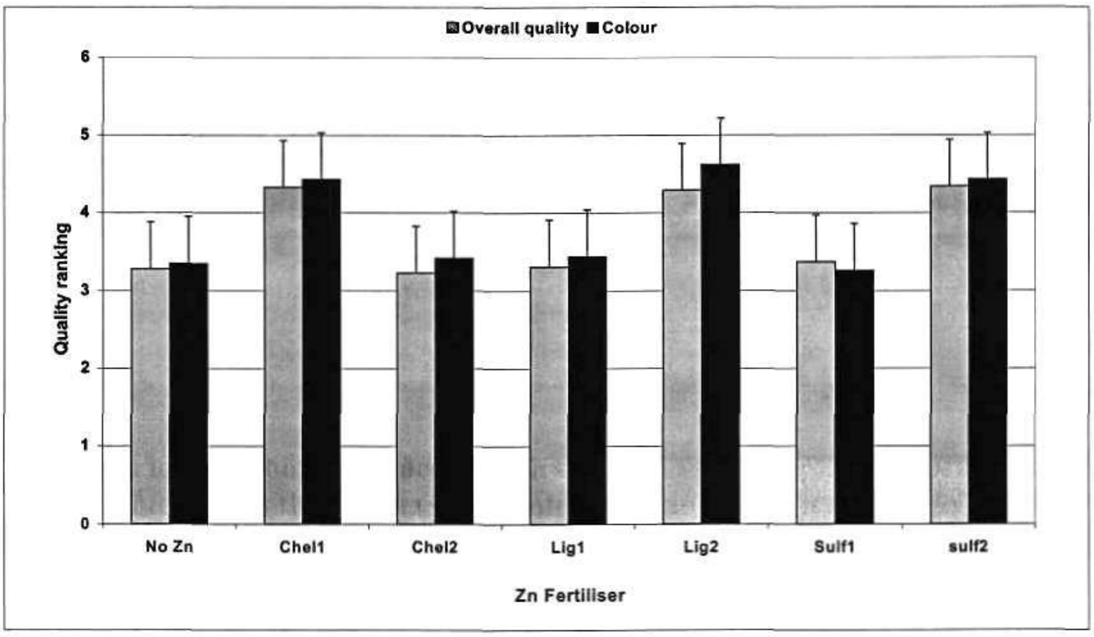

Figure 5. Effect of foliar trace element application on the head colour (black column) and overall quality (grey column) of broccoli at first harvest. Vertical lines are lsd $_{0.05}$ for the relevant quality factors.

5.3.3 Conclusions to the broccoli foliar study

The time of cutting of broccoli, especially the first cutting, is withheld until the number of marketable heads are large enough to justify the cost of cutting without reducing the quality of the produce. Any agronomic practice, which could enhance the maturity and improve the quality of crop, is of value to the growers. The yield and quality response of broccoli to Zn application in this experiment could have commercial application. The differential response to rates and sources of fertiliser indicates that for best result these factors should be appropriately chosen.

The rate of Zn should be relevant to the source chosen. Zinc at 0.5 kg/ha applied as chelate was as effective for yield as1 kg Zn in lignate form and 2 kg Zn in sulfate form. They were equally effective in improving quality at these rates. We do not know whether higher rates, greater than those employed in the experiment, from sulfate and lignate could have increase the yield further. We also did not conduct a cost/benefit analysis to identify the more economical source and rate of Zn. However chelated Zn may not be recommended at higher than 0.5 kg/ha because of the risk of phytotoxicity.

The antagonistic relationships between Zn and Cu frequently reported in the literature (reviewed by Loneragan and Webb 1993), refer to the soil and growth media. We are not aware of these interactions when one is applied to foliage. Further work is necessary to clarify the findings of this experiment.

5.4 Green beans

5.4.1 Methods

Similar to the other experiments, a foliar experiment (TE-19) was conducted on an established green bean crop at FVRS 5 km west of Devonport. The objectives of the experiment were to investigate the effect of application of a single trace element in absence of others in the fertiliser solution.

Soil, a clay loam ferrosol, analysed prior to planting, indicated a low available Zn (Table 6). Boron and Mo were not determined, but the previous season soil analysis report indicated also a low Mo and adequate B. Boron and Mo had not been applied in the past two years prior to this study. The paddock had received 300 kg/ha of DAP band-placed at planting of green beans, cultivar Montano, with inter- and intra-row spacing of 500 and 50 mm respectively (400 000 plants/ha).

Table 6. Soil analysis of FVRS green beans sites before planting

Depth	pH In H_2O	OC (%)	P	K	Zn	Mn	Cu	B
			mg/kg					
0-200 mm	6.7 Ad	4.7 Ad	50 Lo	317 Ad	0.60 Lo	18.8 Lo	1.63 Ad	ND-

ND-not determined

Experimental treatments are given in Table 7. Two foliar applications of B and Mo from one source and Zn from 3 sources, chelate, lignate and sulfate were compared with a control (no foliar fertiliser) and a commercial foliar fertiliser (9-4-6 and trace elements.

Foliar trace elements were sprayed on 16 and 24 January1995, when plants were in full flower. It had been planned to apply the treatments at early bud stage, but weather condition delayed the work.

Table 7. Rates and sources of foliar fertiliser used in the TE18 and TE19 experiments

Treatment	Trade Name	Rate of fertiliser L/ha in each spray	Rate of element kg/ha in each spray	Included in E19
Control	No trace elements	Nil	0	Yes
Zn sulfate (ZnS)	Zincsol	6.00	1.00	No
Zn chelate (ZnC)	Supazinc	6.50	0.50	Yes
Zn Lignate (ZnL)	Thrive-Ag zinc	7.36	0.5	No
Molybdenum	Na-molybdate	0.127	0.05	Yes
Boron	Solubor	1.00	0.20	Yes
Full treatment	Top Foliar	6.25	-	Yes

Plant tissue samples, whole blade and petioles of YFEL were taken two weeks after the second foliar spray. Plant samples were washed, dried and analysed for Cu and Zn by AAS and for other nutrients by ICP.

5.4.2 Results

Although soil analysis results indicated a low available Zn content, and previous soil analysis and paddock history indicated a probable responses to Mo, two foliar applications of Zn and Mo, or a complete fertiliser did not influence the marketable yield (Figure 6), total yield or total fresh matter produced. The yield obtained at this site was 30% higher than the region average. Trace element concentrations in plant tissue increased by application of the elements supplied in the foliar solution. As an example, the change in B concentration due to foliar treatments is given in Figure 6 and showed that even where B was not applied B was in the adequate range. Zinc content of plant tissues without application of Zn (19±1.5 mg/kg) was also in the adequate range for green beans (Reuter and Robinson 1997) and increased to 100 mg/kg when Zn was applied.

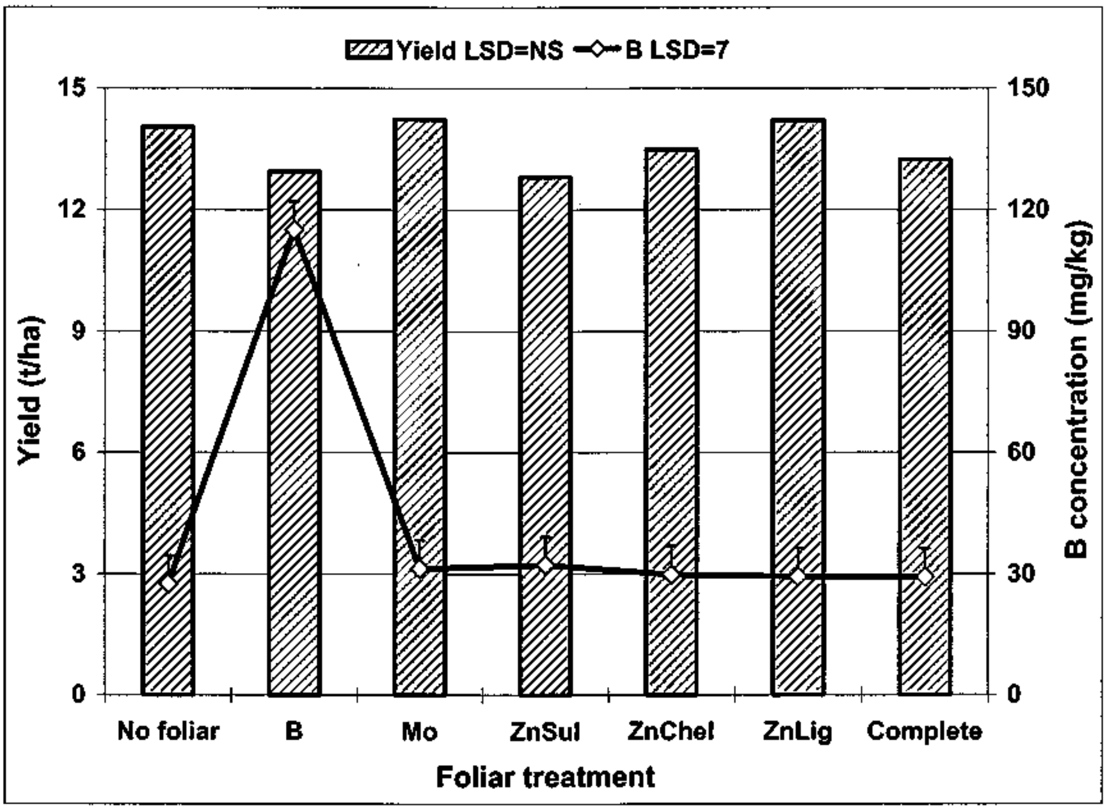

Figure 6. Effects of B, Mo, Zn and a complete foliar fertiliser on yield and B content of green peas tissue at Sassafras site

5.4.3 Conclusions to the green beans foliar study

It appeared that soil test for Zn did not predict the response of green peas to foliar application of Zn. The soil DTPA extractable Zn of 0.6 mg/kg is generally considered deficient for many crops. The lack response to Zn or B application in these experiments may be attributed to may factors including:

8. A fast growing short life crop such as green beans was not given sufficient time to absorb and assimilate the trace elements applied
9. Insufficient amounts of trace elements were supplied by foliar treatments
10. The soil critical Zn concentration for green beans is below 0.6 mg/kg
11. Soil tests cannot identify Zn or B requirements of green beans.

With limited information obtained from these experiments, it is not possible to identify the reason for the lack of response of green beans to Zn and B applications. However, general interpretation standard for plant tissue tests for both trace elements predicted the lack of response better than soil test.

5.5 Green Peas

5.5.1 Methods

A foliar experiment (TE-18) was established on a commercial crop at Sassafras 16 km west of Devonport on a clay loam vertosol. The soil unlike ferrosols of the region became firm and very hard to cultivate when dry. The site had been under pasture for many years prior to 1990 followed by poppies, potatoes and carrots. Very little trace element had been applied to the paddock and soil analysis indicated the soil being deficient in Zn (Table 8). Green peas, cultivar Small Sieve Freezer, were planted on 1 September 1994 at 100 plants/m^2. Prior to planting 250 kg/ha of 3-15-13+Mo had been incorporate into the top 100 mm.

Table 8. Soil analysis results of Sassafras site used for green peas foliar experiment

Site	pH in H_2O	OC (%)	P	K	Zn	Mn	Cu	B
			mg/kg					
Sassafras	6.1 Ad	2.3 Lo	102 Ad	71 Lo	0.65 Lo	77 Ad	0.77 Ad	0.73 Ad

The foliar treatments applied, on 1 and 9 December 1994 at early flowering stage, were the same as those employed at the FVRS site for green beans, except that only one source of Zn, chelate, was used (Table 7). Further details of composition of these fertilisers are given in Table 1.

Plant tissue samples, whole blade and petioles of YFEL were taken two weeks after the second foliar spray. Plant samples were washed, dried and analysed for Cu and Zn by AAS and for other nutrients by ICP.

The crop was harvested on 19 December 1994 and total fresh matter, total and marketable pea yield and pea maturity index were recorded.

5.5.2 Results

Yield of marketable green peas increased by 10% with foliar application of B and it decreased by 20% when Mo fertiliser was used (*P*=0.02). There was no response in yield when other trace elements or the complete fertiliser sprayed on the crop.

The concentration of individual trace elements in plant tissue increased when that element was supplied by foliar application. Boron concentration due to foliar treatment (Figure 7) showed a significant reduction in B concentration when Mo was applied. There was a positive correlation between yield and B concentration in plant tissue (R^2=0.5). The tissue B-yield relationship for the complete treatment did not follow the general trend, probably due to a multiple interaction between the trace and major elements applied.

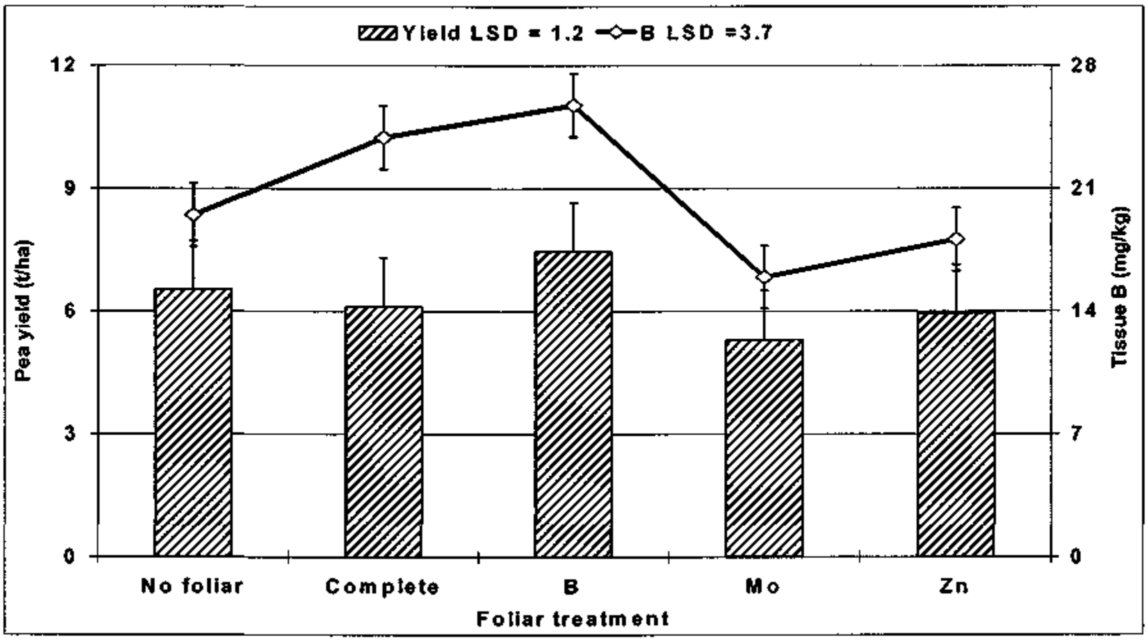

Figure 7. Effects of B, Mo, Zn and a complete foliar fertiliser on yield and B tissue content of green peas at Sassafras site. Vertical lines indicate lsd 0.05 of the means.

Zinc content of plant tissues increased from 19±1.5 mg/kg concentration in the treatments without application to 100 mg/kg when Zn was applied, but it showed no relationships with the yield, probably because it was in the adequacy range for green beans (Reuter and Robinson 1997) in the treatments without Zn application.

5.5.3 Conclusions to the green peas foliar study

As for green beans, the threshold of deficiency for soil Zn commonly employed for other crops didn't apply to green peas for recommending foliar Zn fertilisers. However, DTPA extractable Zn of 0.65 is considered adequate for some crops (Brennan and Gartell 1990) and that might be the case for green peas. The YFEL Zn concentration being in adequacy range without Zn application may support the view that a lower critical soil Zn concentration may be employed for green beans.

Soil B test in this experiment could not predict the yield response to B application. However, the critical concentration of soil hot water soluble B employed in the region is 2 mg/kg, many fold greater that that employed for green peas (0.1 mg/kg) in other countries (Srivastava and Gupta 1996).

5.6 Potatoes, general procedures

5.6.1 Methods

Eight trace element experiments were conducted on potato crops throughout the state during the 1994/95 season. Of these eight experiments, four were single element foliar experiments, three were multiple element foliar experiments and one was a single element, preplant basal and foliar experiment (Table 9). For the basal experiment, although the materials and methods used will be discussed here, the results will be reported later where the basal experiments are discussed.

Table 9. Experiment sites and types.

Site	Code	Chelate treatment	Lignate treatment
Epping Forest	TE-20	Zn, Cu and Solubor B	Cu, Zn, Co, Mo, B ,Ca, Mg
Gawler	TE-21	Zn Chelate	Co. Mo, B, Mg
Low Barrington	TE-22	Cu Chelate	Co, Mo, B, Zn
Sassafras	TE-23	Zn Chelate	Zn, Mo, B
Kindred	TE-24	Zn Chelate	None
Wesley Vale	TE-25	Zn, Cu and Solubor B	Cu, Zn, Co, Mo, B
Paloona	TE-28	Late application Zn, Cu and Solubor B	None

5.6.2 Soil sampling and site selection

Prior to the establishment of each experiment, a soil sample was taken from the experiment site. The sample was made up of 30 cores to a depth of 150mm and each composite sample was analysed for the major and trace elements by the DPIWE and Thrive-Ag laboratories. Results of soil analyses are shown in Table 10. Sites low in one or more trace elements were selected for experiments.

5.6.3 Experimental design and spray application

All experiments were randomised block designs with either 5 or 6 replications. Plot size was 4 rows by 7m (22.4 m²). All foliar experiments were imposed on established commercial crops. Each element in the foliar experiments was applied as a single spray about 6 weeks after planting (tuber size 5-10 mm long) and also as a double spray at about 6 and 8 weeks after planting (Table 11). TE-28 received a single foliar application 10 weeks after planting (Table 11). Zn chelate was applied as Zn- EDTA at 400g Zn/ha, Cu as Cu- EDTA at 300g Cu/ha and B as Solubor or sodium borate at 300g B/ha.

Thrive-Ag supplied a recommendation based on their soil analysis and where possible their recommendation was included as a foliar treatment. It did not necessarily contain the same elements as were applied in other treatments (Table 12). Lignate treatments were applied at 6 weeks after planting in most cases.

All foliar sprays were mixed in tap water, which had been analysed as free of trace elements. The spray rate was 900 L/ha, which wetted the leaf surface but produced very little drip from leaves. Crops were sprayed in the morning to minimise drift. Leaf surfaces had usually dried within 30 minutes

5.6.4 Plant sampling

Forty petioles of the youngest fully expanded leaves (P-YFEL) were sampled from each replicate prior to the first foliar spray when the largest tubers were 5-10 mm long. A second sample of 20 petioles was taken from the control plots and those receiving the double spray. These samples were taken before the second spray was applied to examine the effect, if any, of the first spray. All petiole samples were dried at 70°C, ground in a stainless steel mill, and analysed for B by ICP emission spectroscopy and for Cu and Zn by atomic absorption spectrometry (AAS).

At harvest, 5m of the middle two rows in every plot was harvested. The total tuber yield for each plot was recorded and the tubers were graded according to Edgell factory requirements. The grading categories were <100g, 100-250g, 250-850g, >850g, cut and green and misshapen. The grading at TE-25 also included a badly misshapen category due to the large numbers of such tubers.

Table 10. Soil chemical characteristics of the sites used for potato trials.

Trace elements were analysed by both DPIWE and Thrive-Ag laboratories.

Site	pH	EC	Colwell		Org. C	Mo
	(1:5) water	(1:5) water	P (mg/kg)	K (mg/kg)	(%)	Thrive-Ag (mg/kg)
TE-20	5.3	0.06	10	45	1.7	0.07
TE-21	6.5	-	69	68	-	0.22
TE-22	5.5	-	26	245	-	0.17
TE-23	6.8	0.08	61	73	4.0	0.08
TE-24	6.0	0.12	58	105	4.4	-
TE-25	6.3	0.08	77	65	1.9	0.13
TE-28	5.4	0.03	46	106	3.5	-

Site	Cu (mg/kg)		Zn (mg/kg)		B (mg/kg)	
	DTPA	Thrive-Ag	DTPA	Thrive-Ag	Hot H_2O	Thrive-Ag
TE-20	0.1	0.65	1.0	1.39	0.3	0.27
TE-21	1.1	6.37	1.0	4.28	1.2	0.98
TE-22	0.9	4.69	2.1	4.23	1.1	0.73
TE-23	1.3	8.26	1.2	4.22	1.4	1.32
TE-24	1.5	-	1.2	-	1.4	-
TE-25	0.6	2.45	1.2	2.56	0.8	0.92
TE-28	0.5	-	0.7	-	0.5	-

Table 11. Timetable of operations.

Site	Planting Date	First petiole sampling	First foliar spray	Second petiole sampling	Second foliar spray	Harvest date
TE-20	-	19/12/94	19/12/94	6/1/95	9/1/95	20/4/95
TE-21	5/10/94	29/11/94	29/11/94	13/12/94	14/12/94	6/2/95
TE-22	19/10/94	19/10/94	8/12/94	-	-	29/3/95
TE-23	25/10/94	12/12/94	13/12/94	4/1/95	4/1/95	30/3/95
TE-24	29/10/94	15/12/94	15/12/94	4/1/95	4/1/95	23/3/95
TE-25	24/10/94	12/12/94	15/12/94	4/1/95	5/1/95	27/3/95
TE-28	7/11/94	24/1/95	25/1/95	-	-	10/4/95

Table 12. Details of Lignate treatments (rates in g/ha).

Site	Cu	Zn	Co	Mo	B	Mg	Ca
TE-20	1330	1370	565	920	863	417 x 2	417 x 2
TE-21	-		565	920	863	417	-
TE-22	-	343	283	920	863	-	-
TE-23	-	343		920	575	-	-
TE-24	-	-	-	-	-	-	-
TE-25	665	685	565	920	863	-	-
TE-26	-	-	-	-	-	-	-
TE-28	-	-	-	-	-	-	-

Weights and numbers in each grade were recorded and a 20-tuber sample from the 250-850 category was taken for quality assessment. The quality assessment consisted of determination of specific gravity (SG), bruising index and crisp colour. Tubers from TE 21 were also assessed for common scab.

Table 13. Petiole nutrient concentrations at first

Site	Size of largest tuber (mm)	Petiole nutrient concentrations (mg/kg dw)			
		Zn	Cu	B	Cd
TE-20	hook-8	58	3.9	30	NM[A]
TE-21	5-10	83	4.6	26	4.1
TE-22	5-10	76	5.3	26	1.2
TE-23	5-10	60	3.4	28	1.7
TE-24	5	69	5.8	26	2.5
TE-25	5-10	59	3.8	29	1.5
Radcliff	5	34	4.0	NM	1.7
TE-28	NM	30	5.7	22	NM

[A] NM = not

5.6.5 Harvest

5.6.6 Results

As was the case in 1994, very few significant differences between treatments were observed at any of the experimental sites. No plant top size, habit or colour responses to our treatments were seen. Tables, which summarise results for each experiment, are given in this section. Yield and petiole data are presented for each site, but data on quality are only included where quality was significantly affected.

Table 14. Effect of foliar trace element application on yield and tissue composition of potato from TE-20 experiment at Epping Forest

Nutrient	Nil	Cu-EDTA	Zn-EDTA	Solubor	Thrive-Ag	lsd(0.05)
Total yield (t/ha)	56.5 -	52.2[A] (58.6)	58.8 (50.8)	58.6 (57.4)	56.8 -	NS[B] *P*=(0.28)
Processing. yield (t/ha)	53.4	47.3 (53.2)	54.2 (47.2)	53.7 (53.5)	50.8 -	NS *P*=(0.28)
Petiole Zn (mg/kg)	29	55	54	59	46	**18.3**
Petiole Cu (mg/kg)	2.5	3.1	2.1	3.0	4.2	NS (*P*=0.06)
Petiole B (mg/kg)	30	28	30	30	28	NS (*P*=0.28)

[A] Data in bracket are from plots with double spray, [B] NS = Not statistically significant

5.6.7 TE-20 (Zn, Cu Chelates, Solubor B and Cu, Zn, B, Co, Mo, Ca, Mo lignite)

There was no effect of any treatment on yield or quality at this site despite the 15% difference between the highest and lowest yielding treatments (Table 14), and despite the relatively low soil micronutrient concentrations, especially for Cu and B (Table 10). Variability at this site was increased by the patchy infection of plants with Rhizoctonia. Surprisingly, petiole Zn was increased by all sprays (Table 14). There was no measurable Zn in either the Cu-EDTA or Solubor. These latter treatments gave no measurable increase in petiole Cu or B (Table 14).

5.6.8 TE-21 (Zn Chelate and Co, Mo, B, Mg lignate)

As for TE-20, there were no treatment effects on either yield (Table 15) or quality (not shown). However, Zn-EDTA did increase petiole Zn (Table 15). It did not affect concentrations of other elements measured.

5.6.9 TE-22 (Cu Chelate, and Zn, Co, Mo, B Lignate)

There were no effects of Cu-EDTA or of the Lignate treatment which contained Zn, Co, B and Mo (Table 16). Petiole Cu was slightly increased by Cu-EDTA (Table 16), but the increase was only significant at a probability of 6.8%.

5.6.10 TE-23 (Zn Chelate and Zn, Mo, B lignate)

Again, yields responses were extremely even at this site (Table 17), and quality was generally not affected. There was an increase in chip colour when 2 Zn-EDTA sprays were applied compared to one, and also when Lignate Zn, Mo and B were applied (Table 17). However, the size of the differences was of little practical importance, and was the only such effect observed in this study. Although the average petiole Zn concentration was 6 mg/kg more in the Zn-EDTA treatment compared to the control (Table 17), the difference was not statistically significant (*P*=0.68).

Table 15. The yield and tissue composition results from TE-21 at Gawler.

Treatment	Nil	Zn-EDTA	Zn-EDTA x2	Lignate	lsd (*P*=0.05)
Total yield (t/ha)	52.6	53.3	51.9	52.1	NS *P*=0.95
Proc. yield (t/ha)	46.8	47.9	45.7	48.0	NS *P*=0.95
Petiole Zn mg/kg)	60	67	-	-	5.7
Petiole Cd (mg/kg)	3.5	3.6	-	-	NS *P*>0.05
Petiole Cu (mg/kg)	4.7	4.5	-	-	NS *P*>0.05
Petiole B (mg/kg)	24	24	-	-	NS *P*>0.05

Table 16. Some results from TE-22 at Lower Barrington.

Treatment	Nil	Cu-EDTA	Cu-EDTA x2	ThriveAg	lsd (*P*=0.05)
Total yield (t/ha)	83.4	85.2	85.7	83.9	NS *P*=0.82
Proc. yield (t/ha)	69.0	74.7	76.5	71.7	NS *P*=0.27
Second growth (t/ha)	10.6	6.5	5.8	8.5	NS *P*=0.22
Petiole Zn (mg/kg)	43	41			NS *P*=0.29
Petiole Cd (mg/kg)	1.2	0.9			NS *P*=0.14
Petiole Cu (mg/kg)	3.5	4.1			NS *P*=0.068

Table 17. Some results from TE-23 at Sassafras.

Treatment	Nil	Zn-EDTA	Zn-EDTA x2	Thrive Ag	lsd (*P*=0.05)
Total yield (t/ha)	74.1	73.3	75.0	75.4	NS *P*=0.85
Proc. yield (t/ha)	67.9	67.5	66.4	69.2	NS *P*=0.69
Chip colour	5.6	5.0	6.0	6.2	0.67
Petiole Zn (mg/kg)	59	65	-	-	NS *P*=0.68
Petiole Cd (mg/kg)	1.1	1.0			NS *P*=0.70
Petiole Cu (mg/kg)	3.6	3.8	-	-	NS *P*=0.69

5.6.11 TE-24 (Zn chelate)

Table 18 shows no effects of Zn-EDTA sprays at this site. No Lignate treatment was included in this experiment

Table 18. Some results from TE-24 at Kindred.

Treatment	Nil	Zn-EDTA	Zn EDTA x2	lsd (*P*=0.05)
Total yield (t/ha)	53.3	52.5	52.9	NS *P*=0.93
Proc. yield (t/ha)	45.3	44.3	45.1	NS *P*=0.83
Petiole Zn mg/kg	63.4	63.9	-	NS *P*=0.98
Petiole Cu mg/kg	4.3	4.4	-	NS *P*=0.64
Petiole Cd mg/kg	2.5	2.3	-	NS *P*=0.07

5.6.12 TE-25 (Zn, Cu Chelate, Solubor B and Cu, Zn, Co, Mo, B Lignate)

There were no statistically significant effects of any of the treatments, but the nil had the lowest marketable yield (Table 19). There was a substantial yield of misshapen tubers at this site, about 30-40% of the total (Table 19). Such a result suggests a possible water stress. Whatever the cause, there was a high amount of variability within treatments, such that the 37% increase in marketable yield of the Lignate treatment was not statistically significant.

Petiole analysis showed that both Cu-EDTA and the Lignate treatments increased petiole Cu, but no treatment increased petiole Zn or B (Table 19).

Table 19. Some results from TE-25 at Wesley Vale.

Treatment	Nil	Cu-EDTA	Zn-EDTA	Thrive Ag	Solubor	lsd(0.05)
Total yield (t/ha)	60.0	61.5 (56.2)	60.5 (60.9)	64.5	62.1 (58.3)	NS *P*=0.26
Proc. yield (t/ha)	29.9	32.6 (31.8)	30.6 (32.6)	40.8	34.5 (31.1)	NS *P*=0.44
Second growth (t/ha)	25.6	22.3 (19.0)	26.3 (22.5)	19.5	22.9 (21.6)	NS *P*=0.65
Petiole analyses prior to second spray						
Petiole Zn mg/kg	41	46	38	37	39	NS *P*=0.47
Petiole Cu mg/kg	3.4	4.3	3.3	4.1	3.3	**0.56**
Petiole B mg/kg	30	30	30	30	30	NS *P*=0.98
Petiole Cd mg/kg	1.6	1.8	1.8	1.8	1.8	NS *P*=0.29

5.6.13 TE-28 (Zn, Cu Chelate and Solubor B)

Although the Solubor treatment gave the highest average processing yield (Table 20), the 3 t/ha difference was not statistically significant (*P*=0.42). No petiole samples were taken at this site because of the late spraying (79 days after planting Table 11), and no Lignate treatment was included.

Table 20. Some results from TE-28 at Paloona.

Treatment	Nil	Zn-EDTA	Cu-EDTA	Solubor	lsd (*P*=0.05)
Total yield (t/ha)	63.6	62.7	61.5	65.0	NS *P*=0.41
Proc. yield (t/ha)	46.2	46.2	46.1	49.2	NS *P*=0.42

Table 21. Nutrient concentrations in petioles from commercial crops

Edgell's site	Concentration (mg/kg dw)			Serve-Ag site	Concentration (mg/kg dw)		
ID	**Cu**	**Zn**	**B**	**ID**	**Cu**	**Zn**	**B**
60909	5.9	57	20	9	6.8	52	25
60910	4.3	54	21	16	5.7	47	24
60911	9.9	70	19	17	5.0	57	23
60912	4.1	88	22	18	5.6	49	23
60913	7.8	48	20	19	2.6	49	24
60914	7.2	98	21	20	4.6	52	21
60915	9.8	81	23	21	7.5	33	26
60916	3.7	86	38	22	6.3	71	25
60917	16.2	-	30	23	4.3	34	30
60918	6.0	82	38	24	9.8	88	34
60919	8.5		19	25	6.3	71	21
60920	10.1		20	26	5.2	36	23
60921	10.0	65	21	27	5.5	45	24
60922	6.7		21	28	4.5	67	22
60923	13.0		29	29	3.2	106	26
				32	4.2	46	22
				33	2.5	74	20
				34	3.1	63	23
				35	5.8	53	21

5.6.14 Conclusions to the foliar potato experiments

At all eight potato sites, there was no significant yield response to trace element treatments, and only one minor quality response. This result agrees with that from the basal experiments reported later in this report. There are 3 possible reasons for our negative finding in this work.

1. Our application methods, timing and amounts did not permit real responses to show,
2. Our experimental designs, perhaps through a lack of sufficient replication, were unable to show significant responses,
3. Trace elements were not required by potatoes at our trial sites, and
4. Soils were already adequate in trace elements and a response to trace element fertiliser should not be expected.

1. During the life of this work we applied trace elements as foliar sprays, in a band with NPK fertiliser and in a pre-plant broadcasting. Resources prevented us from comparing all methods for all elements at all sites. The treatments we have used are current practice for many growers. Foliar sprays may not always be as effective as banding or broadcasting on soil, but they have still given increased production in responsive situations (Soltanpour *et al.* 1970). We do not believe we missed out on responses through inappropriate practices.
2. Variation within a trial site affects the sensitivity of experiments. With more variation, the treatment differences have to be larger to be statistically significant. Even the best trial sites have variation which means that small differences (5% or less) go undetected. At 6 of the 8 sites, the yields of different treatments were so similar that we do not believe variability was a limitation. There was simply no response. At TE 20 and TE 25, where disease and other factors increased site variability, more replication may have helped show some differences to be significant. Even so, at TE 20 the nil treatment was one of the best, so it is doubtful that real responses were being masked.
3. Our comments on 1 and 2 above lead us to conclude that potatoes did not need trace element fertilisers at our sites. This is supported by the apparent sufficient levels of Zn and B in petioles when trials were sprayed (Table 13). No reference data for Cu in potato petioles exists by which we can judge the sufficiency of the pre-spray Cu concentrations. Sanderson and Gupta (1990) found 7 mg Cu/kg in leaves to be adequate, but did not have a more deficient situation to test. The petiole status of a number of commercial crops (Table 21) was similar to that at our sites. Petiole Zn in commercial crops was

generally higher. Six crops had petiole B of 20 mg/kg or less (Table 21), which may be of concern. Pregno and Armour (1992) showed a B response of Sebago potatoes when leaves contained 19 mg B/kg.

4. Our soil analysis results when compared with the threshold of deficiency reported in literature suggest that nearly all potato sites we selected were adequately supplied with the trace elements under investigation. In addition, that has been the main factor for finding no responses despite choosing sites lowest in trace elements and which, by current commercial standards, tested low in one or more elements. There seems to be little likelihood that growers will obtain positive responses to trace elements in Russet Burbank potatoes in Tasmania. Furthermore, a negative response is possible, as we found with boron in 1993/94bst year. Sanderson and Gupta (1990) also induced toxicities by spraying potatoes with $CuSO_4$ and $ZnSO_4$ solutions, but at higher rates than we used. Growers need to weigh the odds before deciding to apply trace elements.

The petiole data indicate that caution should be exercised when using petiole analysis to monitor the effectiveness of sprays. Only at some sites did the sprays significantly increase the concentration of relevant trace elements in petioles. At others, the trend was in the right direction, but at some, it was not. Such erratic responses have been observed elsewhere. Soltanpour *et al.* (1970) showed a yield response to Zn despite a lack of response in leaf Zn. Russet Burbank may be a cultivar, which has a particularly poor leaf response to trace elements (Boawn and Leggett 1963).

6 Details of basal trace element experiments.

6.1 Cauliflower (soil and foliar applied Zn, Cu, B and Mo)

6.1.1 Methods

This experiment (TE-15) was established in a commercial paddock at Kindred. The yields of crops on this property have been higher than the average of the region. The soil, a high fertility ferrosol, in the past, regardless of soil analysis results, had received large amount trace element fertilisers regularly. The experimental paddock had been planted with poppy in 1993/1994, and had received B fertiliser.

The objective of this experiment was to compare the efficiency of basal and foliar applied trace element fertilisers on highly fertile soils to which the farmer intended to apply a mixture of Zn, Cu, B and Mo fertilisers. Soil analysis was conducted by two laboratories and the results are reported in Table 22. Treatments included 16 variations of basal and foliar applied fertilisers (Table 23).

Table 22. Soil analysis results (0-200 mm depth) from cauliflower experiment at Kindred

Lab	pH	OC	P	K	Fe	Zn	Cu	Mn	B	Mo
DPIWE Diagnosis	6.8 Ad	4.6 High	163C Hi	351C Hi	36 Ad	4.25 Hi	3.66 VHi	53 Hi	2.52 Ad	-
Thrive-Ag Diagnosis	6.2 Ad	6.3 VHi	12.5O Ad	353E Ad	145E Ad	5.39 VHi	7.37 VHi	201 VHi	2.12 Hi	0.28 VLo

Abbreviations: Ad, adequate; C, Colwell method; O, Olsen method; E, exchangeable; V, very; Hi, high; Lo, low, OC, % of organic carbon, the OC% for Thrive-Ag was calculated from OC = organic matter × 0.58

All plots received 200 kg/ha of a commercial grade diammonium phosphate (18%N, 20% P), except the control treatment. Prior to the planting of cauliflower seedlings cultivar Plana on 3 June 1994, the major and trace element fertilisers were broadcast and lignate solution was sprayed on each plot and incorporated to 150 mm depth using a disc plough. Zinc and Cu were applied in sulfate form, B as Solubor and Mo as either molybdate or lignate (see Table 1 for specification).

Table 23. Basal and foliar treatments ^{A}

Basal treatment	Trace element	Basal +Foliar	Foliar treatment	Rate L/ha
Cont	Control, Nil	Cont+All	Top Foliar	6.25
DAP	Nil	DAP+LMo	Mo Lignate	0.63
All	20 Zn, 10 Cu, 2 B, 0.4 Mo and 200 DAP (kg/ha)	All+All	Top Foliar	5.00
-Zn	All except Zn	-Zn+Zn	Supa Zinc	5.00
-B	All except B	-B+B	Solubor	5.00
-Cu	All except Cu	-Cu+Cu	Supa Copper	5.00
-Mo	All except Mo	-Mo+Mo	Na molybdate	5.00
LAll	All in lignate form (10 L/ha)	Lall+LMo	Mo Lignate	0.63

^{A} For more information on the fertiliser specification see Table 1.

At 14 weeks after planting at buttoning stage (most heads were about 2.5 cm in diameter), the plots were randomly split into two and the foliar treatments as detailed in Table 23 were applied to one half. The foliar treatments were chosen with regard to the basal treatment. Foliar Zn fertiliser, for example, was applied to half of the plots that did not receive basal application of Zn. The LS treatment supplied (in g/ha) 225 Cu, 375 Zn, 37.5 Mo and 8.78 B all in lignate form. The rate and composition of fertiliser used in the LS treatment was recommended by the supplier (Thrive-Ag Ltd.).

Plants were sampled on 28 September 1994 when they were at curd initiation stage. Samples of YFEL were taken from all plots and were analysed for a series of nutrients by ICP and Cu and Zn by AAS.

Harvest, commencing on 21 November 1994, lasted four days. Twenty four plants from three middle rows were selected for harvest. Curds were cut when they were ready for marketing. Individual curds were weighed and assessed for 8 quality criteria, shape, evenness, riciness, colour, firmness, bracts, maturity and hollow heart.

6.1.2 Results

Although the yields of all basal fertiliser treatments were higher than the control, but only DAP increased the yield significantly (Table 24). As all basal treatments receiving trace elements also received DAP, their higher (non-significant) yield increase could be attributed to the effect of DAP. Comparing DAP and LAll treatments (see Table 23 for Description of the treatments), it is evident that basal application of the lignate fertiliser reduced the yield significantly. No visual symptoms of phytotoxicity were observed on the foliage in any treatments. Addition or omission of individual trace elements in basal treatments had no significant effect on the marketable yield and any of the quality criteria studied.

Table 24. Marketable yield of cauliflower (t/ha) as influenced by soil and/or foliar applied trace element fertilisers (lsd basal =4.24, foliar=2.01)

Treat Basal	**Cont.**	**DAP**	**All**	**-Zn**	**-Cu**	**-B**	**-Mo**	**LAll**
Yield (Basal only)	16.860	23.279	20.679	20.360	20.653	19.913	20.666	18.402
Treat Basal +Foliar	**+All**	**+LMo**	**+All**	**+Zn**	**+Cu**	**+B**	**+Mo**	**+LMo**
Yield (Basal +Foliar)	17.050	24.164	22.954	21.509	18.413	19.868	23.182	20.254

All foliar treatments especially +Mo foliar treatments tended to increase the yield over the counterpart basal treatments, but there was only significant yield increase when Mo was applied as Na-molybdate to the –Mo basal treatment, which had not received basal Mo. The lowest yields of treatments receiving basal DAP and foliar trace element was obtained in the foliar Cu treatment, showing the possibility of Cu toxicity. Soil analysis results indicate that soil Cu was very high and probably had approached its toxicity threshold and yield results may confirm this prediction.

Plant composition of the YFEL samples taken before foliar treatment showed no significant changes with application of basal DAP or trace elements (Table 25). There has been no report on the trace element composition of cauliflower tissues from work in Australia (Reuter and Robinson 1997). However, the summary of the trace element composition of YFEL reported here for general information, fell in the adequate range of those reported from other countries.

Table 25. Composition of youngest fully expanded leaves (including petioles) of cauliflower cv. Plana at buttoning stage[A]

	P	**Ca**	**Mg**	**K**	**Na**	**S**	**Zn**	**B**	**Mn**	**Cu**	**Fe**
	(%)						**(mg/kg)**				
Mean	0.38	1.94	0.35	3.22	0.09	0.43	27	16	64	2.9	87
Maximum	0.59	3.32	0.63	3.92	0.15	0.51	38	20	102	4.5	510
Minimum	0.31	1.11	0.23	2.39	0.06	0.32	21	12	43	1.7	46
Stand Error	0.03	0.24	0.03	0.12	0.01	0.26	2.7	1.0	7.8	0.42	48

[A] Curd diameter 2.5 cm± 0.5 cm.

The minimum B concentration in YFEL in the treatment without B, was below or near the critical concentration for deficiency of 25 mg/kg suggested by Gupta (1979) and 11 mg/kg observed by others (Reuter and Robinson 1997), yet there was no response to basal or foliar applied B.

Molybdenum deficiency was predicted by soil analysis and when basal Mo had not been applied (*eg* in DAP basal treatment) a significant increase in yield was attained by a foliar application of Mo. Where a range of other trace elements was supplied the response to Mo might have been neutralised probably by Cu presence. Zinc was predicted by soil analysis to be adequate and was confirmed by the yield results.

6.1.3 Conclusions to the cauliflower basal study

Soil test results predicting Mo deficiency and adequacy of other elements, which were in conformity with the results of the experiments showed that the test could be employed for recommendation of trace elements to cauliflower. The reduction of yield with application of a complete range of trace elements also showed that the common practice of use of a range of trace element fertilisers without due attention to the soil test may not always serve as an "insurance policy", but be a liability. Because of the interaction of trace elements, we concluded that if Mo alone had been applied in this experiment, the yield increase could have been larger than what was attained.

Plant tissue tests, contrary to what was observed with other crops, and for reason unknown to us, did not show any response to the high rates of soil-applied trace elements and P. The tissue and sampling time chosen were conventional.

6.2 Carrots (soil-incorporated sources of B, Zn and Cu)

Trace element fortified trace elements are commonly recommended to carrot crops and perceived to improve yields but specifically the quality of carrots. Although soil analysis is conducted for some paddocks prior to sowing, the recommendations are routine and not always relevant to the test results. During 1993-95 seasons, more than fifty farms in northwestern Tasmania were contracted by the processing companies to grow carrots. The soil test results from those paddocks was used to identify two sites for our investigation. The sites' soil concentrations of Zn, Cu or B were the lowest that could be found amongst 25 farms available for experiments. The crops at both paddocks, as recommended to the farmer, would receive 500 kg/ha of commercial grade 14-16-11 (N-P-K + Full trace elements)

The objectives of this experiment were to study the effect of soil applied Zn, Cu and B on the yield and quality of carrots on the sites to which normally trace element fertilisers would have been applied and to compare the efficiency of different sources of Cu and Zn

6.2.1 Method

Two trials were conducted in commercial carrot crops in northwestern Tasmania near Devonport (41 ° 12' S, 146° 22'E). One of experiments (TE-4) was established in Jan 1994 at Kindred 15 km southwest of Devonport in a paddock with a continuous vegetable cropping history of potatoes, *Brassica* crops, peas and poppies. The other experiment was established on 21 October 1994 at Wesley Vale 8 km west of Devonport in paddock with a cropping history of long term pasture and potato. The soils at both sites were deep clay loam ferrosol and were situated on flat well-drained land. The cultivars sowed were Frantes at Wesley Vale and Red Flame at Kindred. Soil analysis was conducted by two laboratories and the results are reported in Table 26.

Table 26. Topsoil (0-150 mm) test results from carrot experiments at Kindred and Wesley vale analysed by DPIWE and Thrive-Ag laboratories.

Lab	Site	pH	OC	P	K	Fe	Zn	Cu	Mn	B	Mo
DPIWE	Kindred	6.6	4.6	173C	242C	36	2.6	3.21	37	1.52	-
		Ad	Hi	Hi	Ad	Ad	Ad	Hi	Ad	Ad	
Thrive-Ag	Kindred	6.6	6.3	10.5O	240 E	252 E	5.03	6.4	157	1.35	0.46
		Ad	VHi	Marg	Ad	Hi	VHi	VHi	VHi	Marg	VLo
DPIWE	Wesley vale	6.5	3.2	125 C	248 C	85	1.07	0.58	64	1.35	-
		Ad	Ad	Ad	Ad	Ad	Marg	Marg	Ad	Ad	
Thrive-Ag	Wesley vale	6.6	3.9	8.5 O	258 E	253	5.0	6.9	170	1.6	0.17
		Ad	Hi	Marg	Ad	VHi	VHi	VHi	VHi	Ad	VLo

For abbreviations see Table 22

At Wesley Vale, prior to planting, 500 kg/ha of commercial grade 14-16-11 (N-P-K) and the experiment trace elements were broadcast or sprayed on the plots and were incorporated into the top 150 mm topsoil. In a randomised block design 8 treatments consisting of control (no trace element) a complete fertiliser and 3 sources each of Zn and Cu were employed with four replicates. Boron was applied only as Solubor, whereas Zn and Cu were each applied as chelate, lignate or sulfate (Table 27). The rates of Zn and Cu were chosen based on the common recommendation for those compounds.

Table 27. The composition and amounts of fertilisers used in the carrot experiment

Sources[A]	Solubor (B)	Supa copper (CuC)	Supa zinc + (ZnC)	Cu-Lignate (CuL)	Zn-Lignate (ZnL)	$CuSO_4.H_2O$ (CuS)	$ZnSO_4.7H_2O$ (ZnS)
Element (kg/ha)	2	1	2	1	2	10	20

[A] For more information about these fertilisers see Table 1.

At Wesley Vale on 19 January 1995, when roots were about 10 mm in diameter and 100 mm long (mid-growth), tissue samples were taken. Twenty plants were pulled randomly, and their tops were removed, washed, dried, ground and analysed for the major and trace elements. The experiment site was harvested on 2 March 1995.

At Kindred the trace elements treatments consisted of a control and 6 different lignate fertiliser solutions (Table 28) at rates recommended by the supplier. Prior to sowing of carrots, 500 kg/ha of a commercial grade fertiliser (11-12-19, N-P-K) was broadcast and the trace element fertilisers were sprayed on the plots and incorporated into the top 150 mm of soil using a disk plough. No plant tissue samples were taken from the Kindred crop. The crop was harvested on 21 June 1994. For both sites the root quality, including external, core, shoulder and margin colour, splitting, and deformities were recorded.

Table 28. The composition of lignate fertilisers[A] used at Kindred carrots experiment

Treatment Name	Description
Control	No basal trace element fertiliser
Full traces [FT]	25 L liquid lignate trace element fertiliser, providing (in kg/ha) 1.125 Cu, 1.875 Zn, 0.187 Mo and 0.878 B
Deficient treatments [FT]-one trace element	Four treatments, each providing three of the four trace elements Zn, Cu, Mo or B.
Complete	NPK + trace elements

[A]For more information on the composition of fertilisers see Table 1.

6.2.2 Results

At Kindred, where all trace elements were in lignate form, there was no response to the application of any trace element, even Mo that was identified to be deficient by Thrive-Ag. At Wesley Vale where soil Cu and Zn where diagnosed to be marginally low, there were yield increases with application of Zn and Cu, but not from all sources (Figure 8). Application of Cu-sulfate, Cu-lignate and Zn-sulfate increased the yield by 23, 26 and

28% respectively. Boron and other sources of Zn tended to increase yield, but the differences were not significant at 5% probability level.

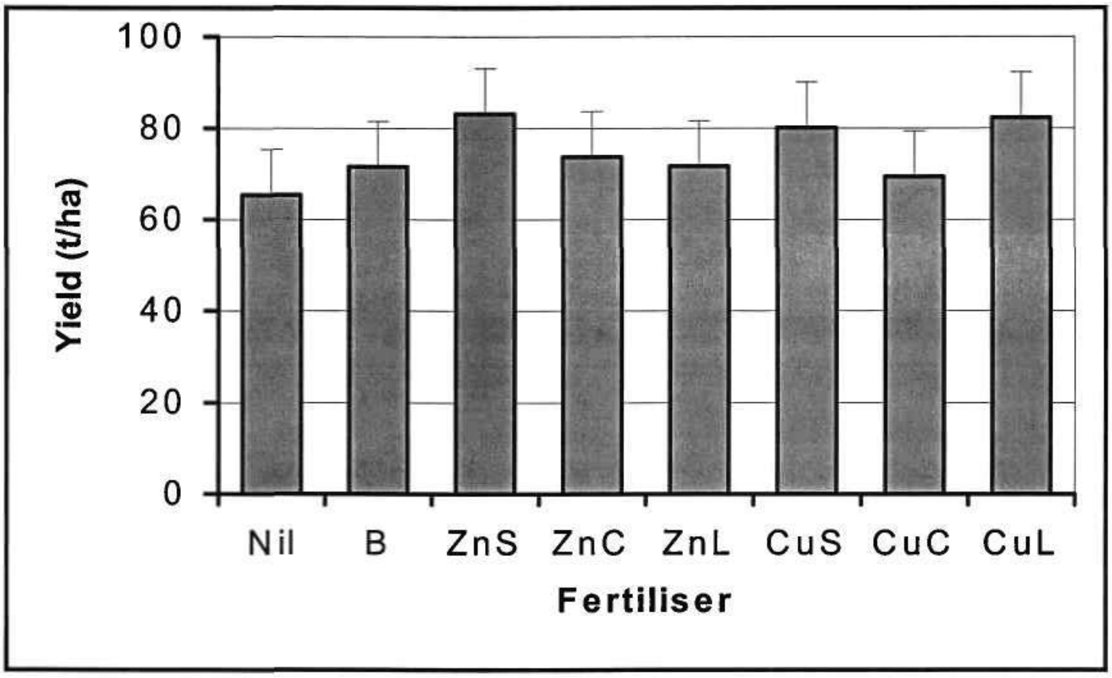

Figure 8. Effects of soil applied trace elements on yield of carrots at Wesley vale. Cu and Zn were applied in sulfate (S), chelate (C) and lignate (L) forms.

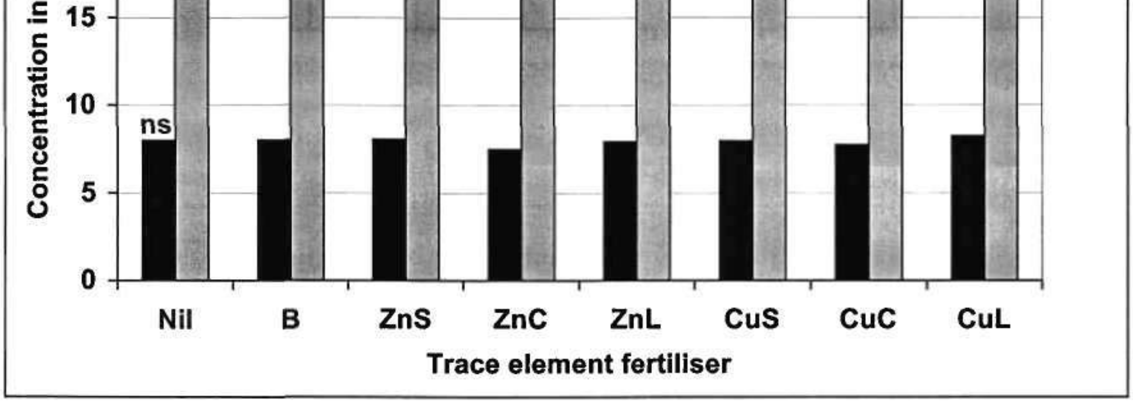

Figure 9. Effects of soil applied trace elements on Zn and Cu concentration in the YFEL of carrots at Wesley vale. Cu and Zn were applied in sulfate (S), chelate (C) and lignate (L) forms.

Concentrations of Cu in YFEL were not affected by application of any of the fertilisers and remained at about 8 mg/kg (Figure 9). The concentration of Zn was only increased in the $ZnSO_4$ treatment that produced the highest yield in the experiment (Figure 9). Carrot root quality was not affected by any treatment in either experiment.

6.2.3 Conclusions to the carrot basal study

The resposes attained in this experiment were the only yield resposes observed to application of Zn or Cu in many experiments conducted on different vegetable crops. The condition of the experiment was somehow different from other experiments in that the DTPA soil test for Zn and Cu indicated that the soil was marginally low in both those elements and the fertilisers at high rates were incorporated into the soil prior to planting. The efficiency of different sources of trace elements is difficult to study, because they are not applied at same rate. The rates we employed in these and most other experiments were those recommended by the suppliers and were near to the rates recommended in the literature. Whether the rate employed for the other sources has been the cause of the lack of response is not known at this stage.

6.3 Broccoli

6.3.1 Method

This experiment (TE-6) was established at Kindred on a commercial crop. The crop beyond the experiment area received 750 kg/ha of 14-16-11 with trace element supplement (Table 1), and two foliar of a complete foliar fertiliser containing both major and trace elements (Top Foliar). The DPIWE soil analysis (Table 29) did not show any need for the use of trace elements. However, Thrive-Ag soil test indicated Mo, B and Zn deficiencies. This experiment was conducted to study the yield and quality responses of the crop to trace elements

The experimental design was a randomised block design with 7 treatments and four replicates. The treatment consisted of a control, a full lignate traces, four treatments deficient in one of the trace elements (see Table 28 for more information) and a treatment receiving trace element supplement, 5 kg of mineral trace elements as for the commercial crop.

Table 29. Topsoil (0-200 mm) analysis results of site used for broccoli experiment[A]

Lab.	**pH water**	**Organic C %**	**P**	**K**	**B**	**Mo**	**Zn**	**Cu**	**Mn**
			(mg/kg)						
Thrive-Ag	5.48	5.8	11.3	281	0.75	0.13	4.1	4.67	122
	V Lo	V Hi	Marg	Ad	Lo	V Lo	Marg	Ad	Hi
DPIWE	5.9	4.4	89	300	1.30		2.28	2.1	53
	Lo	Ad	Marg	Ad	Ad	Nd	Ad	Ad.	Hi

[A] Methods of soil analysis are described in section 1.4.5. Abbreviations: Ad = Adequate, Hi = High, Marg = Marginal, Lo = Low, V = Very; Nd, not determined

Before transplanting of broccoli cultivar Marathon on 9 February 1994, the basal NPK fertiliser (750 kg/ha 14-16-11) and the trace elements were broadcast or sprayed on the soil and incorporated into the top 150 mm of soil. Plant tissue samples, whole YFEL, were taken at head initiation on 25 March 1994.

The crop was harvested sequentially four times from 22 to 29 April 1994 as heads reached marketable size and the weight and the quality of heads were recorded. The main harvest date was on 26 April. The head quality factors, hollow heart, colour, browning, starring, compactness and presence of bracts were ranked 1 to 5. A rank of 1 represented desired and 5 most undesired quality. The mean ranking of all quality criteria was then calculated.

6.3.2 Results

Application of fertiliser containing all trace elements in either mineral or lignate form did not influence the yield, but when the fertiliser was deficient in either Zn, B or Mo yield was reduced by up to 20% (Figure 10). When Cu was omitted from the mix, there was no yield reduction. This indicated that Cu toxicity might have been the cause of yield reduction, and application of a balanced blend reduced the damage caused by Cu. However, this argument is not supported by tissue composition, since there was no effect of fertiliser treatments on the concentration of any of trace elements (data not shown). Trace element treatments did not influence the quality of carrot roots except when all trace elements were applied as lignate, which the mean quality was reduced.

6.3.3 Conclusions to the Broccoli basal study

As was reported above for other vegetable crops it appears that application of Cu to the soil adequate or high in Cu may cause reduction in yield and the use of other trace elements in combination with Cu may reduce the ill effect of Cu.

6.4 Sweet corn

Maize and sweet corn are considered to have a high demand for Zn and would benefit from Zn application when soil DTPA extractable Zn is about 1 mg/kg or lower. The site in this trial had been identified as Zn and B deficient after the first soil analysis report was received from the Incitec Laboratory. Soil sampling was repeated from the experiment area and was analysed by our laboratory. The results are reported in Table 30. Analyses from, both laboratories indicate that soil Zn levels were not adequate. In most soils, band-placed fertilisers are more efficiently utilised by crops than when applied as broadcast. The objective of this experiment was to study the effects of band-placed B and Zn fertilisers on yield and quality of sweet corn.

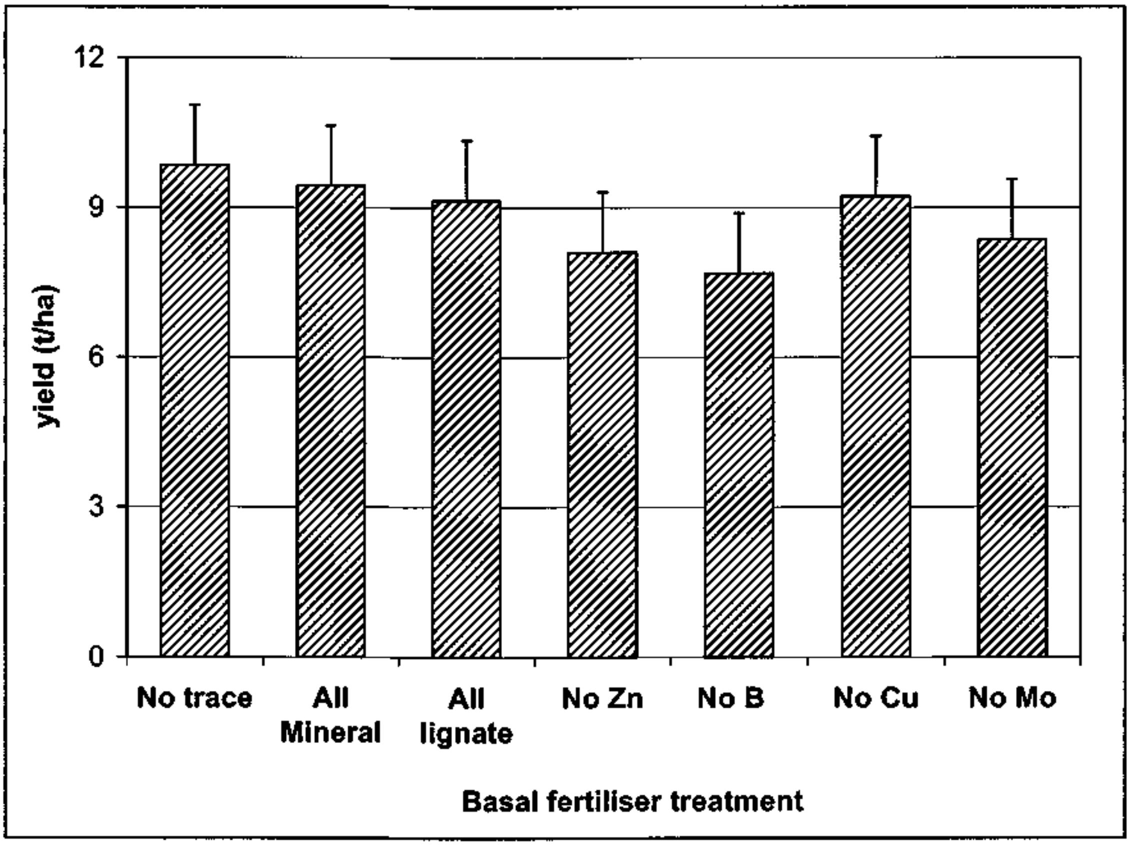

Figure 10. Effect of complete lignate or mineral fertilisers and omission of one trace element on marketable yield of Broccoli at Kindred

Table 30. Soil analysis results from sweet corn experiment at Merseylea (TE-5)[A]

Lab	pH water	OC (%)	Fe (mg/kg)	Zn	Cu	Mn	B	Mo
DPIWE	5.7 Acid	2.2 Lo	282 Ad	1.29 Marg	1.05 Hi	48 Ad	0.26 Ad	-
Incitec	5.2 Acid	1.7 Lo	Nd	0.5 Lo	1.2 Hi	32 Ad	0.33 Lo	0.28 VLo

[A]Methods of soil analysis are described in section 1.4.5. Abbreviations: Ad = Adequate, Hi = High, Marg = Marginal, Lo = Low, V = Very; Nd, not determined

6.4.1 Methods

Sweet corn, cultivar Jubilee, was sown on 14 November 1994 with row spacing of 800 mm and intra-row spacing of 250 mm, giving rise to 4.6 plants/m^2. Trace elements, at the rate given in Table 31, were uniformly mixed with 1 kg wetted attapulgite clay and 2 kg of a commercial grade 14-16-11 fertiliser (equivalent to 700 kg/ha) and band-placed at sowing. Plot dimensions were 4.8 by 6 m and contained six plant rows.

Table31. The composition and amounts of fertilisers used in the sweet corn experiment

Sources[A] →	Solubor (B)	Supa zinc + (ZnC)	Supa zinc + (ZnC)	Zn-Lignate (ZnL)	Zn-Lignate (ZnL)	$ZnSO_4.7H_2O$ (ZnS)	$ZnSO_4.7H_2O$ (ZnS)	Control
Element (kg/ha) →	1	0.5	1	0.5	1	10.5	21	No Trace

[A] For more information about these fertilisers see Table 1.

On 2 February 1995, when plants were at tasselling stage, the leaves below and opposite primary cobs were sampled, dried and ground. Copper and Zn were determined by AAS procedure.

On 10 March 1995, all primary and secondary cobs from 26 plants on two middle rows were handpicked. Cob weights with and without husk and cob quality including length, diameter, row-evenness and tipfill were determined for both primary and secondary cobs.

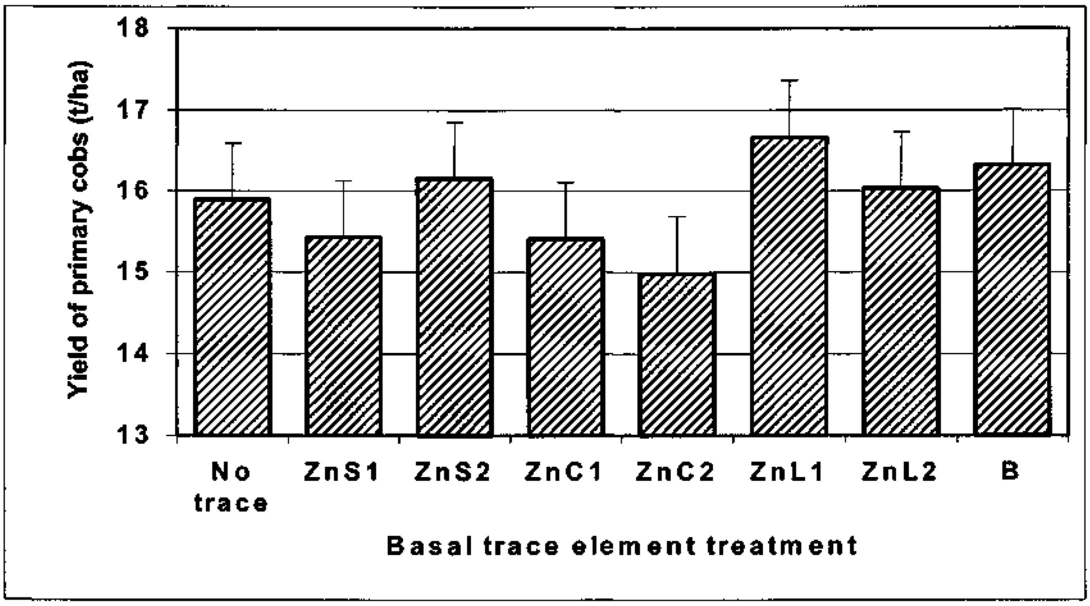

Figure 11. Effect of rate and source of basal trace elements on yield of primary cobs of sweet corn

6.4.2 Result

The soil B was diagnosed to be adequate by us and low by the commercial laboratory (Table 30). Application of B tended to increase primary cob yield, but the differences were not statistically significant (Figure 11). Boron addition did not influence the secondary and total yields either.

Application of 0.5 kg Zn as lignate increased the primary cob yield slightly (5%) and doubling the rate tended to decrease the yield. Zn chelate reduced the primary yield and had no effect on the secondary cob yield. The highest decrease in yield (6%) occurred when 1 kg Zn was applied as chelate. At tasselling stage in that treatment leaves were pale in colour and some showed tip and edge-burns. No toxicity symptom was observed in any other treatment. Zinc sulfate did not have any effect on either primary or secondary cob yield.

Mean Zn concentration in YFEL was high in all treatments (74 mg/kg), but in the adequate range reported by Jones *et al.* (1991). The concentration of Zn in YFEL in the treatment which received 1 kg Zn/ha as chelate, was 137 mg/kg, 3 times that of the control (Figure 12). From these results, it was concluded that the reduction of yield in the Zn chelate treatment was due to Zn toxicity. YFEL Zn concentration in the $ZnC1_2$ treatment was also higher than other treatments.

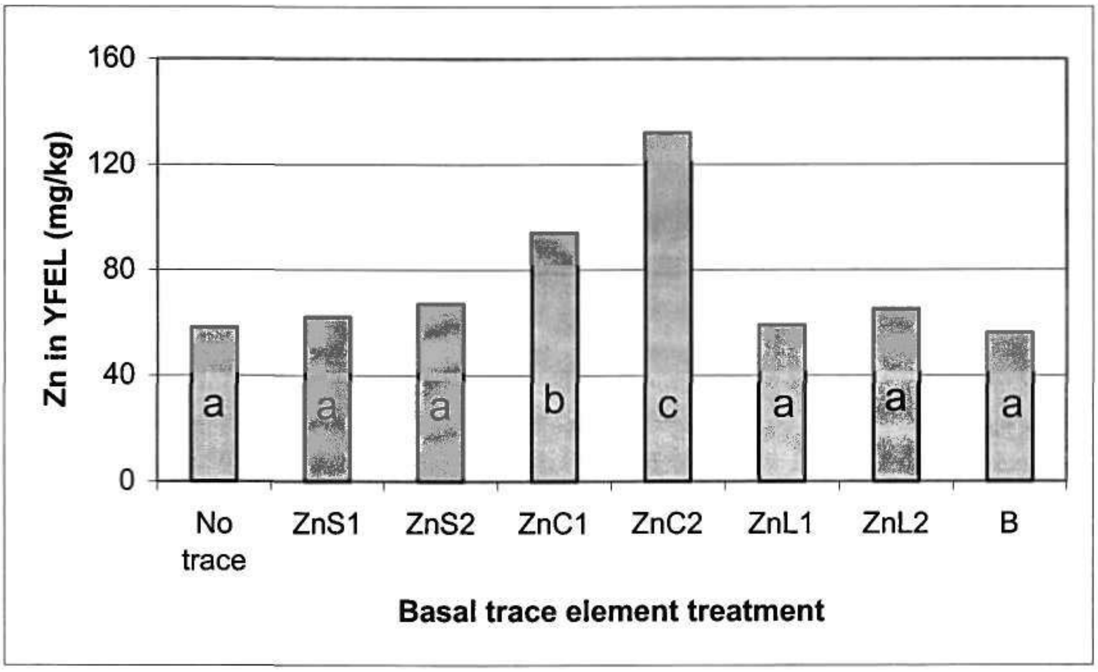

Figure 12. Zn concentration in YFEL at tasselling stage of sweet corn as influenced by B and Zn application.

Application of Zn did not influence Cu concentration in YFEL. Even in the ZnC2 treatment with symptoms of Zn toxicity, the Cu concentration (8.6 mg/kg) remained similar to that in other treatments.

6.4.3 Conclusions to the sweet corn basal study

In this experiment there was no relationship between the YFEL concentration of major and trace element and yield or the quality of sweet corn. The critical deficiency concentration of soil HWSB may vary with crops. As reported by Srivastava and Gupta (1996), while the HWSB of 0.5 mg/kg may be considered to be deficient for *Brassica* crops, other crops such as corn, potatoes, legumes and cereals do not respond to B application at soil B concentrations above 0.1 mg/kg.

Synthetic chelates of Zn are the most effective Zn sources and are 3-5 times more effective than $ZnSO_4$ (least efficient) for many crops (Mortvedt and Gilkes 1993). Natural organic complexes such as Zn lignate used in this experiment are somewhere in between those sources (Mortvedt and Gilkes 1993). If increases in plant tissue Zn could be taken as an index for the availability of Zn from different sources, Zn chelate would be more than 30 times more available than the same amount of Zn from the $ZnSO_4$ source.

Although the critical concentration of Zn in plant tissue varies with plant species and the tissue (Mortvedt and Gilkes 1993), it remains about 20 mg/kg in YFEL and young leaves. The concentration of Zn in YFEL of control plots in this experiment was more than two folds greater than those reported in the literature and there was still a yield response to the application of Zn lignate. The soil Zn test indicating a deficiency was in conformity with yield response observed. The lack of response to Zn chelate might have been due to the phytotoxicity of chelate, but inefficiency of 10 or 20 kg Zn as Zn SO_4 is difficult to explain.

6.5 Potatoes

6.5.1 Methods

Four field experiments investigating the effects of basal or basal in combination with foliar trace element applications were completed in 1993/95. Each experiment was a randomised block, split-plot experimental design with 5 replicates. Three sites (Morris and Langton and Radcliff) were on ferrosols at Kindred, Sunnyside and Wesley Vale respectively, and the other, Winton, was on wind-blown sand about 10 km north of Campbell Town. Some site characteristics are shown in Table 32

Basal inorganic trace element (BTE) fertilisers plus one commercial lignate mixture were main plots, and foliar trace elements from lignate or partly chelated source were sub-plots. Main plot size was six rows by 12 m. The basal treatments are shown in Table 33.

Table32. Some site characteristics.

SITE	pH 1:5 H20	EC dS/m	Colwell P (mg/kg)	Colwell K (mg/kg)	Org C (%)	DTPA-Cu (mg/kg)
Winton	6.1	0.06	5	146	0.8	0.6
Wesley Vale	6.4	0.12	115	450	5.5	1.4
Morris	6.5	0.05	127	194	4.8	2.5
Langton	6.3	0.06	32	401	5.0	2.1
	Thrive-Ag Cu	**DTPA-Zn**	**Thrive-Ag Zn**	**HWSB**	**Thrive-Ag B**	**Thrive-Ag Mo**
	(mg/kg)					
Winton	1.12	0.6	0.48	0.3	0.04	0.21
Wesley Vale	-	0.9	-	1.5	-	-
Morris	6.06	2.1	3.63	1.3	1.26	0.11
Langton	6.33	2.5	3.72	1.7	1.34	0.18

Table33. Basal treatments

Treatment	Composition
Nil	No trace element
All	Containing Cu, Zn, Mo and B applied as follow: 10 kg Cu/ha as coarse crystalline (2-5 mm) copper sulfate (25% Cu) 20 kg Zn/ha as granulated (2-3 mm) zinc oxysulfate (35% Zn) 0.46 kg Mo/ha as fine ground sodium molybdate (46% Mo) 4.0 kg B/ha as granulated (2-3 mm) sodium tetraborate pentahydrate (14%B)
-Zn	As for All but without Zn
-Mo	As for All but without Mo
-B	As for All but without B
-Cu	As for All but without Cu
Lignate	A commercial liquid mix supplying (in g/ha) 310 Zn, 7 B, 190 Cu and 31Mo

The inorganic BTE were broadcast on cultivated soil a few days before final cultivation and planting (Table 34). Lignate was applied as a spray to soil at the recommended 10L/ha.

FTE were applied either as lignate TE (Morris and Langton) or as partly-chelated TE (Winton), at rates recommended by the suppliers (3.47 L/ha) (Tables 34, 35).

The banded, broadcast and foliar Zn experiment (Radcliff) conducted at Wesley Vale was planted using a Faun planter. Three rates of Zn (2.5, 5.0 and 10.0 kg Zn/ha) as zinc sulfate were either broadcast on cultivated soil and incorporated using a rotary hoe prior to planting or band placed with NPK at planting. The foliar treatment was a double spray applied to plots, which had received no other Zn. Irrigation, pest and disease management on all sites was by the growers. The growers applied no trace elements.

Table 34. Timetable of operations

SITE	BTE applied	Planting date	Petioles sampled	FTE applied	Harvest date
Winton	15/10/93	19/10/93	15/12/93	17/12/93	13/4/94
Radcliff		26/10/94	13/12/94	13/12/94	27/4/95
Morris	3/11/93	20/11/93	6/1/94	13/1/94	13/1/94
Langton	10/11/93	13/11/93	4/1/94	12/1/94	11/5/94

For Radcliff the second petiole sampling and foliar application was on 4/1/95

Table 35. Rates of foliar applied trace elements in g/ha

SITE	Cu	Zn	B	Mo
Winton	210	260	350	2.0
Radcliff[A]	300	400	300	-
Morris	190	240	26	90
Langton	190	240	26	90
Lignate (all sites)	190	310	7	31

[A] Zn and Cu applied as EDTA complex and B as Solubor.

Crops were planted by growers using their normal commercial seed, fertiliser, and machinery. The subsequent irrigation, pest and disease management were also conducted by the growers. No trace elements were applied by growers.

Forty petioles of youngest fully expanded leaves (P-YFEL) were sampled from each of the inner rows of each main plot just prior to application of FTE, when the largest tubers were 5-20 mm long. Petioles were dried at 70°C, ground in a stainless steel mill, and analysed for B and Zn by ICP emission spectroscopy, and for Cu, Zn and Mo by atomic absorption spectrometry (AAS).

At harvest, the middle 4 m of two inner rows from each sub-plot was harvested, except at Winton. At Winton variable plant density due to poor emergence and rhizoctonia unrelated to treatments (these could also be seen elsewhere in the commercial paddock) restricted us to as little as 4 m of row in total in some sub-plots, and necessitated the exclusion of 8 sub-plots from the experiment.

Total tuber yield from each sub-plot was recorded, and tubers were then graded into five grades of 100g, 100-280g, 280-450g, >450g and misshapen. Weights and numbers in each grade were recorded, and a 5 tuber subsample from the 280-450 g grade taken for quality assessment, which consisted of determination of specific gravity (SG), bruising index and crisp colour.

6.5.2 Results

Very few significant differences between treatments were observed at any of the sites (Tables 36, 37, 38). Perhaps the most important was at Winton where it appears that basal application of B induced B toxicity (Table 36). Petiole B was lowest in the absence of basal B (nil and -B treatments), while processing yield was highest in these 2 treatments (Table 36). Total yield was also highest in these treatments at this site, but the differences between treatments were not statistically significant. Pregno and Armour (1992) showed that 8 kg B/ha, when banded with NPK fertiliser, induced B toxicity in Sebago potatoes grown on a ferrosol in north Queensland, while only 2 kg B/ha increased yield by 38% compared with no B. This shows the fine line between B deficiency and toxicity. We had not expected 4 kg B/ha broadcast to be toxic, especially where the soil hot water B was only 0.3 mg/kg (Table 32), but the Winton site was very sandy, which would have aided B mobility and uptake compared with a ferrosol. Pregno and Armour (1992) showed that 19 mg B/kg in YFEL 7 weeks after planting was deficient, 24-26 mg B/kg was sufficient and more than 30 mg B/kg was toxic (Table 39).

Table 36. Some results from Winton (TE9)

Treatment	**Nil**	**All**	**-Zn**	**-B**	**-Cu**	**-Mo**	**Lignate**	**lsd 0.05**
Proc Yield	**42.0**	35.7	38.1	**43.7**	28.2	32.9	32.5	8.01
Bruise index	**3.4**	2.4	2.9	2.9	2.8	2.7	2.5	0.45
Internal browning	0.50	0.05	0.28	0.25	0.33	0.10	**2.10**	0.99
SG	1.082	1.083	1.081	**1.079**	**1.084**	1.082	**1.079**	0.004
Petiole Zn	57	57	57	62	54	64	58	NS
Petiole B	**21**	30	30	**23**	30	28	25	4.4

All yields in t/ha; all petiole concentrations in mg/kg dm. Shading shows significant treatments.

Table 37. Some results from Langton (TE8)

Treatment	Nil	All	-Zn	-B	-Cu	-Mo	Lignate	lsd 0.05
Proc Yield	44.2	48.7	47.8	48.1	45.3	45.0	43.6	NS
Yield 100-280g	31.1	32.8	28.4	30.7	32.8	**25.5**	26.4	4.81
Yield 280-450g	8.0	9.4	11.3	10.4	7.5	**12.0**	10.1	2.97
Bruise index	5.4	5.6	5.5	5.2	5.5	5.6	5.4	NS
SG	1.089	1.089	1.087	1.089	1.090	1.090	1.088	NS
Petiole Cu	5.2	5.4	5.4	5.3	5.0	5.5	5.5	NS
Petiole Zn	101	101	89	82	82	91	90	NS
Petiole B	23	24	24	23	24	23	25	NS
Petiole Mo	0.27	0.37	0.38	0.43	0.39	0.31	0.42	NS
Petiole Cd	0.79	0.80	0.75	0.69	0.75	0.72	0.76	NS

All yields in t/ha; all petiole concentrations in mg/kg dm. Shading shows significant treatments.

At Winton, there was a high incidence of misshapen tubers, and spraying *per se* increased the yield of misshapen tubers from 11.9 to 14.6 t/ha. At Morris, application of Zn decreased the yield of large (>450g) tubers (Table 38), but only by a small amount, and without affecting the processing yield (Table 38). Similarly, at Langton, it appeared that application of everything but Mo shifted some yield from 100-280 g tubers to 280-450 g tubers (Table 37), although processing yield was unaffected. There were no other notable effects of BTE or FTE on yield or its components at any site.

There were inconclusive effects of BTE on SG at Winton and Morris (Tables 36 and 38). BTE which contained everything but Cu gave the highest SG at these sites, while BTE which had everything but B gave the lowest SG (Tables 36 and 38). At Morris, the subsequent follow up spray with lignate TE (both the complete commercial mix and -Zn) depressed SG significantly ($P<0.05$) where lignate sprays of other treatments did not (Table 40). These effects are difficult to explain. SG at all sites was quite acceptable.

Application of BTE decreased bruising at Winton (Table 36), but the magnitude of the decrease was of little commercial importance. At Langton, the follow up spray with the commercial lignate mix decreased the incidence of bruising ($P=0.04$) compared with the other lignate sprays, but again the magnitude of the decrease was small (Table 41). Also at Winton, Lignate trace elements applied as a basal dressing gave a higher incidence of tuber internal browning (Table36), while reapplication of the Lignate trace elements as a foliar spray increased the incidence of hollow heart from 0.01 to 0.76 ($P=0.058$, Table

42). Other FTE had no significant effect on hollow heart relative to their BTE counterparts (Table 42).

Table 38. Some results from Morris (TE-7)

Treatment	Nil	All	-Zn	-B	-Cu	-Mo	Lignate	lsd 0.05
Proc Yield	43.6	43.0	44.8	45.6	45.0	45.0	45.7	NS
>450g	3.8	3.3	**4.4**	2.5	3.0	2.9	3.0	1.01
Bruise index	5.9	5.9	6.3	6.1	5.5	6.3	6.0	NS
SG	1.092	1.092	1.091	**1.090**	**1.095**	1.090	1.091	0.003
Petiole Cu	4.4	4.5	4.3	4.5	4.3	4.9	4.6	NS
Petiole Zn	67	65	57	73	70	71	71	NS
Petiole B	24.0	23.9	23.9	23.9	23.3	23.5	24.0	NS
Petiole Mo	0.39	0.39	0.40	0.41	0.46	0.31	0.34	NS
Petiole Cd	1.31	1.27	1.20	1.15	1.25	1.29	1.33	NS

All yields in t/ha; all petiole concentrations in mg/kg dm. Shading shows significant treatments.

Apart from B at Winton, there were no significant effects of BTE on petiole TE or Cd concentrations in P-YFEL (Tables 36, 37, 38), although there was a tendency for treatments lacking a certain element to be lower than others containing it. It appears that on the ferrosols especially, broadcast BTE were not very effective at increasing petiole micronutrient concentrations, which may reflect immobilisation in these soils. Applied rates which were at the high end of the range of rates broadcast to good effect on other crops elsewhere (Martins and Westermann, 1991) to try and counter this sort of effect, but perhaps did not go high enough. Banding a lower rate of these fertilisers may have proved more successful than broadcasting, but would have meant much more work in experiment establishment. Using fine ground rather than coarse or granulated sources of Cu, Zn and B, and using the more soluble $ZnSO_4$ instead of Zn oxysulfate may also have been better.

Table 39. Summary of previous work on trace elements in potatoes

Element	kg/ha	Application method	Source	Response?	Cultivar	Soil	Foliar conc Nil to +TE	Plant part	Notes	Reference
Zn	5.6	banded	$ZnSO_4$	no	Sebago	s loam	33 to 32	petiole		Vinande et al 1968
Zn	25	broad	$ZnSO_4$	no	Russet Burbank	s loam, pH 5-5.8	21 to 27	YFEL-petiole 10 days pre-bloom	0.5-1kg foliar Zn toxic	Sanderson & Gupta 1990
Zn	2.2 8.9 11.1 11.1 11.1	band band band disc band	ZnEDTA $Zn\ SO_4$ $Zn\ SO_4$ $Zn\ SO_4$ $Zn\ SO_4$	yes yes yes yes no	Russet Burbank	s loam free lime	23 to 33 23 to 29 9.6 to 14 9.6 to 13 11.8 to 19.2	4th & 5th leaves 59DAP 4th & 5th leaves 64DAP 58 dap		Soltanpour et al 1970
Zn	11.1	broad	$ZnSO_4$	yes	Russet Burbank	silt loam pH 7.2	10 to 17	leaves	severe defic.	Boawn & Leggett 1963
B	1	broad	Borate-65	No	Russet Burbank	fine s loam	23 to 28	4th & 5th leaves 10% bloom	0.3-0.6 mg/kg Mehlich3 B	Gupta & Sanderson 1993
B	2-4 8-12	band band	Na Borate	yes yes:toxic!	Sebago	krasnozem	19 to 24-26 19 to 30-31	YFEL 42DAP	0.7 HWSB	Pregno & Armour 1992
B	2.2-9 2.2	broad band	Na borate	No Yes toxic!	Russet Burbank	silt loams pH 6.9-7.5			0.3-0.4 mg/kg B	Roberts & Rhee 1990
Cu	25	broad	$CuSO_4$	no	Russet Burbank	s loam, pH 5-5.8	7.2 to 7.9	YFEL-petiole 10 days pre-bloom	0.5-1kg foliar Cu toxic	Sanderson & Gupta 1990
Cu	5.6	banded	$CuSO_4$	no	Sebago	s loam	7.1 to 6.4	petiole		Vinande et al 1968

Table 40 Effect of spraying on specific gravity at Morris

Treatment	BTE only	BTE+FTE
Lignate - All	**1.093**	**1.089**
All	1.092	1.092
-Zn	**1.093**	**1.089**
-B	1.092	1.089
-Cu	1.094	1.096
-Mo	1.089	1.092

lsd 0.05 = 0.0038 (shading indicates significant differences)

Table 41. Effect of spraying on bruising at Langton

Treatment	BTE only	BTE+FTE
Lignate - All	**5.99**	**4.81**
All	5.53	5.56
-Zn	5.36	5.65
-B	4.96	5.43
-Cu	5.70	5.20
-Mo	5.55	5.57

lsd 0.05 = 0.755 (shading indicates significant differences)

Table 42. Effect of spraying on hollow heart at Winton

Treatment	BTE only	BTE+FTE
Lignate - All	**0.01**	**0.76**
All	0.01	0.01
-Zn	0.07	0.07
-B	0.21	0.46
-Cu	0.01	0.01
-Mo	0.21	0.21

lsd 0.05 within treatment = 0.40

Although it appears that the BTE were not effective on the ferrosols, the petiole Zn and B concentrations in the nil treatments at Morris and Langton suggest that responses to these elements would have been unlikely. Critical deficiency levels for Zn and B observed elsewhere for potatoes have been 20-30 mg Zn/kg and <20 mg B/kg (Table39), below the concentrations observed at our sites, although direct comparisons with this data are difficult because of differences in plant part and age at sampling. However, we also applied extra of all elements as FTE which should have elicited any response not given by BTE. While 2 foliar applications are often needed for maximum yield, one spray still provides a measurable response (Soltanpour *et al.* 1970). We are therefore reasonably confident that no positive yield responses to B and Zn were seen at these sites because none were to be had in this season. We did not sample petioles after spraying because of restrictions on labour and laboratory resources, and because of the uncertainty about surface residues masking true uptake.

Table 43. Petiole micronutrient concentrations (mg/kg) for NE Tasmanian Russet Burbank crops in 1993/4.

Sample	Zn	B	Sample	Zn	B
1	45	27	10	43	26
2	30	27	11	44	28
3	36	21	12	33	**18**
4	44	**18**	13	32	29
5	71	20	14	45	26
6	32	21	15	43	28
7	40	21	16	42	20
8	48	25	17	31	23
9	51	27			

Shaded cells have either Zn < 30 mg/kg or B < 20 mg/kg

Table 44. Petiole micronutrient concentrations (mg/kg) for 35 NW Tasmanian Russet Burbank crops in 1993/4.

Sample	Zn	B	Sample	Zn	B
8 12 10	33	32	16 12 27	43	26
8 12 11	30	32	16 12 28	37	29
8 12 12	39	31	16 12 29	51	33
8 12 13	40	26	16 12 30	**17**	32
8 12 14	69	30	16 12 31	55	30
8 12 15	84	28	16 12 33	64	27
9 12 27	45	25	16 12 34	88	27
9 12 28	55	26	16 12 35	**28**	**19**
9 12 31	60	31	16 12 36	37	33
9 12 32	60	31	16 12 37	55	26
9 12 33	49	31	16 12 38	38	33
9 12 34	**21**	31	16 12 39	42	28
9 12 35	40	28	20 12 19	45	27
13 12 01	47	30	20 12 20	49	30
13 12 02	40	25	20 12 21	40	30
13 12 03	41	29	20 12 22	69	24
13 12 04	64	26	20 12 23	37	28
13 12 05	57	29			

Shaded cells have either Zn < 30 mg/kg or B < 20 mg/kg

There is very little data elsewhere on either petiole or yield responses to Cu (Table 39) and none on Mo. Our petiole data suggest that >4 mg Cu/kg and >0.3 mg Mo/kg is adequate, but these are tentative conclusions at this stage. The low rate of foliar Mo applied at Winton (Table 36), due to miscalculation, may have restricted a Mo response. We need to see the petiole Mo concentrations before judging this further.

A number of petiole samples from commercial crops in the NE and NW were analysed for micronutrients to see how representative our experiment sites were. The analyses of commercial crops are shown in Tables 43 and 44. The data from commercial potato crops suggest that last year only a small proportion of them were likely to respond to B or Zn, and further, that many were well in the sufficiency range for these elements. This is especially so given that several of the NE samples were from crops with largest tubers 25 to 70 mm long (M Coote, pers. comm.). These potatoes would likely have had higher petiole B and Zn when they were at a stage comparable with our experiment samples (5-20 mm).

At Radcliff site, there was no effect of Zn application by any method on yield (Figure 13) or quality (data not shown), although banded Zn increased petiole Zn concentrations and broadcast Zn tended to do the same (Figure 14). Analysis of the leaf lamina separate from the petioles showed no such pattern (Figure 14). Because Zn has been shown to affect Cd uptake, tuber and petiole Cd were measured, but there was no effect of Zn in this experiment on these measures (Figures 15).

6.5.3 Conclusions to the potato basal experiments

Three basal experiments in one season are only a limited sample. Nevertheless, when taken alongside the results of foliar experiments and the analyses of petioles from commercial Tasmanian crops, the results from these experiments indicate that responses by potatoes to B and Zn are unlikely to be widespread in Tasmania. They also sound a warning that B toxicity is possible on sandy soils. We may need to rethink interpretation criteria for micronutrient analyses of soil B and Zn. Because of the lack of published data on potato responses to Cu and Mo, and the unavailability yet of petiole Cu and Mo analyses from all of our experiments, it is difficult to relate the lack of response to Cu and Mo to the probability of such responses generally.

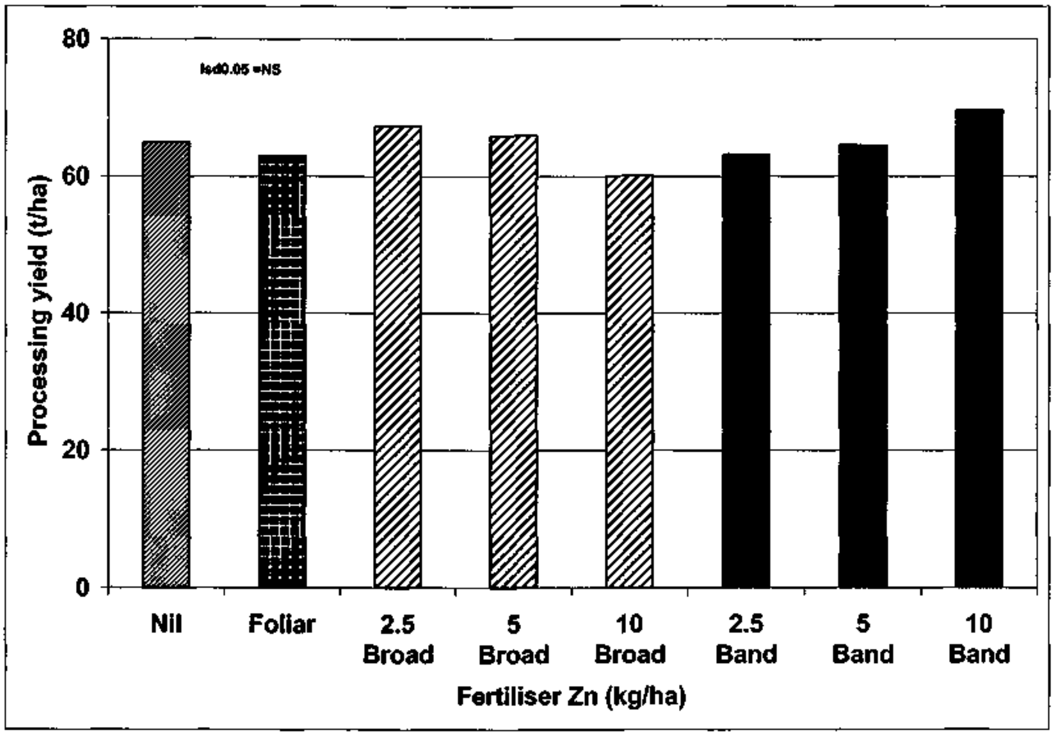

Figure 13.Effect of foliar and different rate of banded (Band) or broadcast (Broad) fertiliser Zn on yield of potatoes at TE-26.

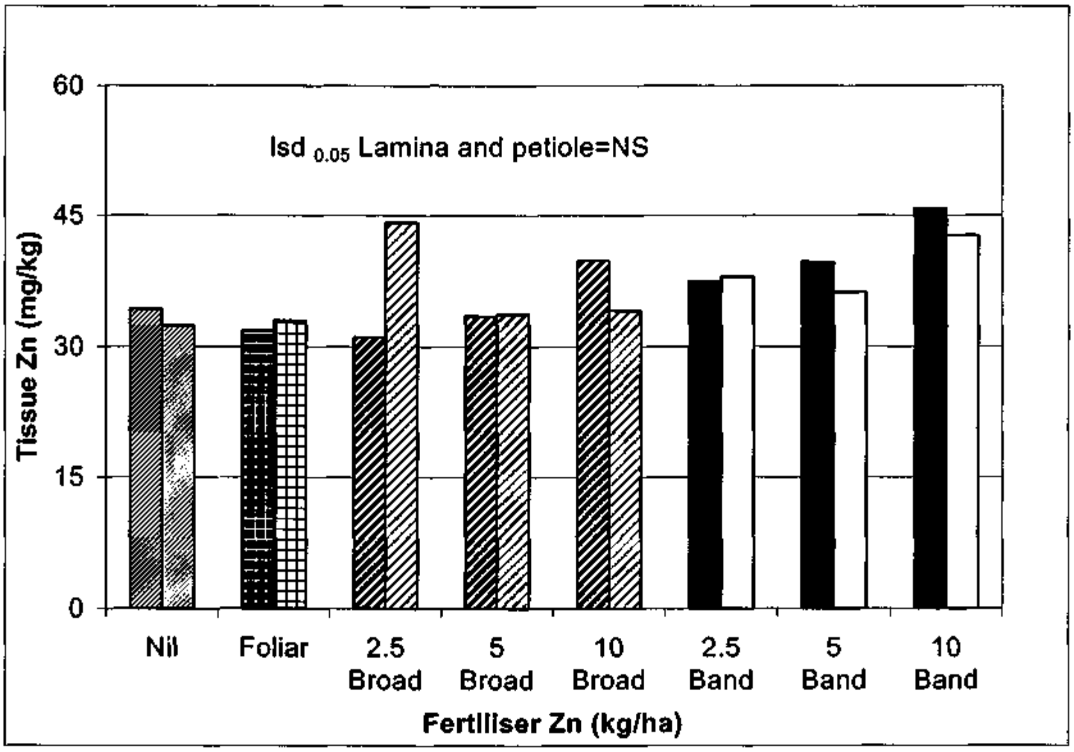

Figure 14.Effect of foliar and different rate of banded (Band) and broadcast (Broad) fertiliser Zn on the Zn concentration in petiole (left column of the pairs) and lamina (right column) of potatoes at TE-26.

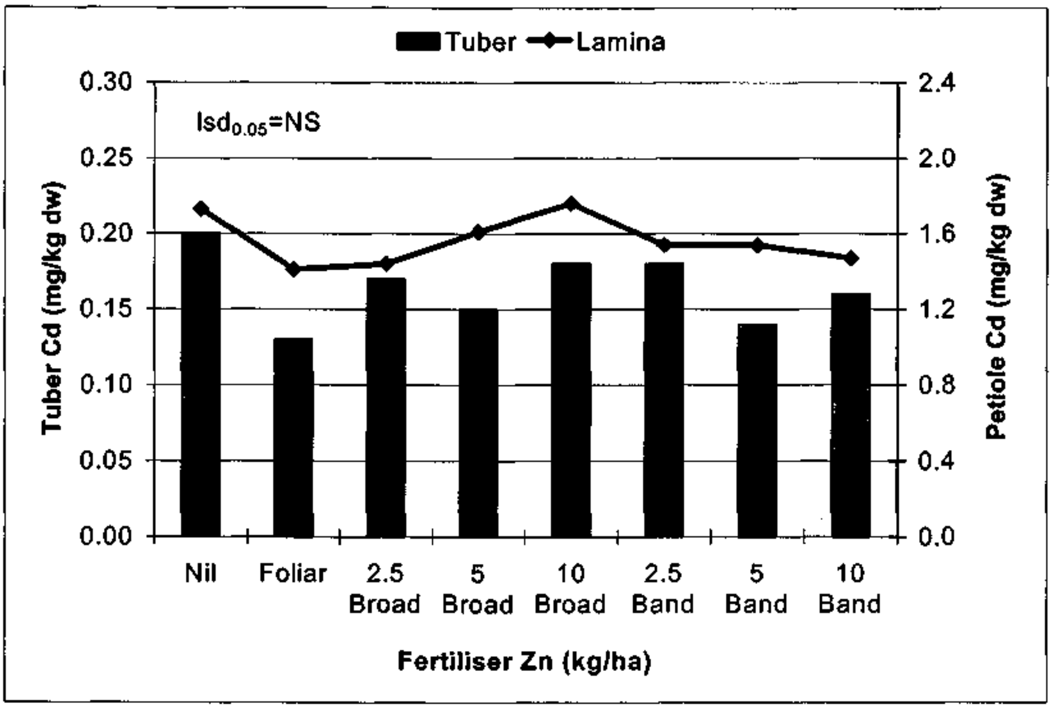

Figure 15.Effect of foliar and different rate of banded (Band) or broadcast (Broad) fertiliser Zn on Cd concentration in tuber (column) and lamina (line) of potatoes at TE-26.

7 Project discussion

7.1 Yield or quality response

Because of routine application of trace elements in the past two decades, most long-established vegetable farms are probably sufficiently supplied with trace elements Zn, Cu and Mn. The soil analysis results from the commercial soil laboratories and our own works clearly support this statement. The likelihood of obtaining a yield or quality response to application of Zn, Cu and Mn in these farms is therefore very small. Since mobile trace elements such as B and to a lesser extent Mo, are not accumulated in the soils under normal cropping, only recent fertiliser application history influences the soil available B and Mo and the response of crops to these trace elements.

Although we selected sites with the lowest trace element content, in 171 combinations of treatments resulted from foliar and/or basal application of different sources of four trace element fertilisers to different crops, there was only 9 positive or negative yield or quality responses.

Table 45. Summary of the yield and quality responses to foliar application of trace elements B, Zn, Cu, Mo and Mn and the value of soil or plant analysis in predicting crop response to foliar application of trace elements.

Crop	Experiment	Trace element form	Criteria	B	Zn	Cu	Mo	Mn
Poppy	TE-2	Lignate	Yield	×	↑	↓	↑	×
			Soil		+D 1.0	+A 2.5		+A 69
			Plant	+A	+A	+A		+A
Sweet corn	TE-5	Lignate	Yield	×	×	×	×	×
			Quality	×	×	×	×	×
			Soil	+A	-D 0.8	+A 2.6		+A 129
			Plant	+A	+A	+A		+A
Broccoli	TE14	Lignate, mineral, chelate	Yield	×	×	×	×	×
			quality	×	↑	×		×
			Soil		+D 0.65			
			Plant		+A			
Green beans	TE-19	Lignate, mineral, chelate	Yield	×	×		×	
			Soil		-D 0.6			
			Plant	+A	+A	+A		+A
Green peas	TE-18	Mineral	Yield	↑	×		↓	
			Soil	-D 0.73	-D 0.65			
			Plant	+D A	+A			
Potato	TE-(20,22,23,24,25,28)	Lignate, chelate	Yield	×	×	×	×	
			Quality	×	×	×	×	
	TE-(20,21, 28)		Soil	+A 0.3	-D 0.7	-D 0.1		
	TE-(22,23,24,25)			+A	+A	+A		
	TE-(20,22,23,24,25,28)		Plant	+A	+A	+A		

Symbols used are ↑, yield increase; ↓, yield decrease; ×, no effect on yield or quality; + and -, correct and incorrect prediction of yield response in A adequate and D in the deficient range. Threshold of deficiency in mg/kg soil taken were DTPA-Zn, Cu and Mn=1, 0.3 and 65; HWSB=0.1 for potatoes, corn, peas and beans, 0.5 for *Brassica* crops.

Table 46. Summary of the yield and quality responses to basal application of trace elements B, Zn, Cu, Mo and Mn and the value of soil or plant analysis in predicting crop response to basal application of trace elements.

Crop	Experiment	TE form	Criteria	B	Zn	Cu	Mo	Mn
Cauliflower	TE-15	Lignate	Yield	×	×	×	↑	
			Soil	+A 2.5	+A 4.2	3.7+A		
			Plant	+A	+A	+A		
Carrots	TE-4	Lignate, mineral, chelate	Yield	×	↑	↑	×	
			Quality	×	×	×	×	×
			Soil	+A 1.5	+D 1.0	-D 0.6		+A
			Plant	+A	+D	+A		+A
Broccoli	TE-6	Lignate, mineral	Yield	×	×	↓	×	
			Quality	×	×	×	×	
			Soil	+A 1.3	+A 2.3	+A 2.1		
			Plant	+A	+A	+A		
Sweet corn	TE-17	Lignate, mineral, chelate	Yield	×	↑↓			
			Soil	+A 0.3	+D 0.5			
Potato	TE-(7, 8, 9)	Lignate, mineral	Yield	×	×	×	×	
			Quality	↑	×	↓	×	
			Soil	+A 0.3	-D ≤0.9	+A		
			Plant	+A	+A	+A		

Symbols used are ↑, yield increase; ↓, yield decrease; ×, no effect on yield or quality; + and -, correct and incorrect prediction of yield response in A, in the adequate and D deficient range. Threshold of deficiency in mg/kg soil taken were DTPA-Zn, Cu and Mn=1, 0.3 and 65; HWSB=0.1 for potatoes, corn, peas and beans, 0.5 for *Brassica* crops.

In a foliar poppy experiment (TE2), when from a complete solution (containing Zn, Cu, B and Mo), either Zn or Mo was omitted, there was a yield reduction and this was coincided with high Cu concentration in the YFEL. In a green peas experiment (TE18), the yield increased by 10% with foliar B application and reduced by 20% when Mo solution was sprayed. In the TE-15 experiment, basal and foliar treatments were combined. In that experiment when Mo was not included in the basal fertiliser, its foliar application increased the yield of tubers by 12%, but in the same experiment application of Cu as foliar only, reduced the yield by 12%.

Positive responses (23-28% yield increase) were attained in one of the two carrot sites (TE-4) with the soil incorporation of Zn or Cu at planting. Similar to the TE-2 experiment, application of a complete fertiliser mix (containing Major and trace elements) as either foliar or basal treatment in the TE-6, did not have any effect on yield or quality of broccoli. However, the mixes containing Cu, but not Zn, B or Mo produced yields about 20% lower than the control. Sweet corn in the TE-17 experiment showed quality improvements with 0.5 kg Zn-chelate/ha, but at 1 kg Zn-chelate/ha, there was a 6% reduction in yield and development of tip and edge burning and leaf yellowing.

In all 11 potato experiments, there was no significant yield response, minor quality responses to basal, foliar and combinations of basal and foliar applications of trace elements, except at TE-9. In that experiment, the broadcast dressing of a trace element mix containing 4 kg B/ha prior to planting of Russet Burbank potatoes, produced a yield 8 t/ha (20%) less than when B was not included in the mix.

7.2 Soil tests

This study showed that, when the interpretation criteria presented in the recent Australian soil analysis manual (Peverill et al. 1999) were used, soil analysis gave reasonable predictions of soil trace element status. The predictions were more accurate where crop species and soil group were taken into account.

Of the 7 non-potato sites with soil Zn-DTPA of 1.0 mg/kg or less, four sites (carrots, cauliflower, broccoli and sweet corn) responded in yield or quality to foliar or basal application of Zn fertilisers. None of the 4 potato sites with similar soil Zn content showed any significant yield response to trace element treatments, and only 1 minor quality response. Armour and Brennan (1999) from the studies in Australia and elsewhere, suggested the critical soil DTPA critical concentration for most crops to be in the range of 0.3-0.55 mg/kg.

Based on Armour and Brennan (1999) review and the results of our own work, we conclude that, until detailed soil Zn calibration studies are undertaken, the soil DTPA critical concentration may be set for the vegetable crops as summarised in Table 47.

Table 47. Interpretation of soil DTPA-Zn test for vegetable crops in north western Tasmania and similar regions

Soil DTPA-Zn (mg/kg)	Soil status	Crop	Response
≤ 0.3	Very deficient	All vegetables	Very likely
0.3-0.55	Deficient	Most vegetables	Likely
0.55-1.0	Marginal	Few vegetables	Likely in near neutral soils
1.0 and greater	Sufficient	All crops	Unlikely

Soil HWSB concentrations from 15 sites were above 1 mg/kg, which is considered to be adequate for all crops (Bell 1999) and no responses were observed. The HWSB of all remaining sites, but one, were below 1 mg/kg and above the threshold of B deficiency for the crop investigated. In those ranges of soil B, a crop response to B application is possible, but the probability is not great. In our experiments, peas (soil B=0.73 mg/kg) responded in yield to foliar B application, and potato (soil B=0.04 mg/kg) showed a quality improvement with soil B application. Table 48 summarises the soil HWSB interpretation for crop response to B fertiliser.

Table 48. Interpretation of soil HWSB test for vegetable crops in north western Tasmania and similar regions

Soil HWSB (mg/kg)	Soil status	Crop	Response
≤ 0.3	Very deficient	All vegetables	Very likely
0.3-0.5	Deficient	Most Brassica vegetables	Likely
0.5-1.0	Marginal	Poppy	Likely
		Other vegetables	Unlikely
<1.0	Sufficient	All crops	Unlikely

A yield response to Mo was observed with foliar application of Mo to poppy and soil incorporation for cauliflower. As soil Mo tests are difficult to conduct and are not always reliable predictors for soil Mo status, we did not attempt to evaluate those tests.

We recommend the application of Mo fertiliser prior to establishing crops such as beans, peas, and *Brassica* vegetables. One application of Mo fertiliser in 3-4 year rotations, supplies sufficient Mo to sustain healthy supply of Mo to other crops in the rotation.

Soil DTPA-Cu concentration of our sites ranged between 0.1 and 3.2 mg Cu/kg and no response to foliar or soil applied Cu was observed, except in our carrots experiment (TE-4). The soil Cu-DTPA at this site was 0.58 mg/kg and with basal application of Cu-sulfate more than 23% yield increase was attained. On a soil with DTPA-Cu of 2.4 mg/kg, foliar application of Cu lignate, in the absence of Zn or Mo in the foliar solution, reduced the yield of poppy due to Cu toxicity. The high YFEL and seed Cu concentrations confirmed the Cu toxicity.

At another site with DTPA-Cu concentration of 2.1 mg/kg, basal application of a mixture containing Cu did not affect the yield of broccoli. However, omission of Zn, B or Mo from the spray mix decreased the yield indicating Cu induced trace element deficiencies.

Calibration of soil Cu tests with the vegetable yield response to Cu application is usually conducted in pot trials, but Rayment (1993) from a field survey, suggested that soil DTPA Cu concentration of >0.1 were very low, 0.1-0.3 low and 0.3-5 mg/kg as medium for most vegetables. The low ranges are similar to those reported by others (Brennan and Best 1999), The medium range falls within the adequate range for most crops reported by others (Brennan and Best 1999). We suggest Table 49 would be more applicable to the soils and vegetable crops in north-western Tasmania.

Table 49. Interpretation of soil DTPA-Cu test for vegetable crops in north western Tasmania and similar regions

Soil DTPA-Cu (mg/kg)	Soil status	Crop	Response
≤ 0.1	Very deficient	All vegetables	Very likely
0.1-0.3	Deficient	Most vegetables	Likely
0.3-1.0	Marginal	Few vegetables	Occasionally likely
1.0 or greater	Sufficient	All crops	Unlikely, may induce Zn or other deficiencies

7.3 Plant analysis

The youngest fully expanded leaf or its petioles were sampled in nearly all experiments. Sufficient time lapsed between foliar applications and sampling to make sure that the new tissues that had appeared after application of fertiliser were emerged and fully developed before being sampled. This prevented physical contamination, and ensured that changes in tissue composition reflected the absorbed and translocated nutrients. Only at some potato sites did the sprays significantly increase the concentration of relevant trace elements in petioles. At others, the trend was in the right direction, but at some, it was not. Russet Burbank may be a cultivar that has a particularly poor leaf response to trace elements (Boawn and Leggett 1963). In a foliar broccoli experiment, application of different rates of Zn from different sources had no effect on the YFEL Zn concentration. In the poppy experiment, foliar trace element applications increased the concentration in both YFEL and seeds showing that poppies could readily absorb trace elements and translocate them within the plant.

When trace elements were applied to the soil, changes in the composition of YFEL were not always observed. The concentration of trace elements in cauliflower YFEL did not change with the soil incorporated trace elements. However, Zn concentration in the YFEL of corn and carrots increased with the application of soil applied Zn fertilisers.

In all experiments where no response to trace element application was observed, the concentration of trace elements in the YFEL fell in the adequacy range as compiled for those crops in the Australian plant analysis handbook (Reuter and Robinson 1997). Six Russet Burbank potato crops had petiole B of 20 mg/kg or less and no response to B was observed. Pregno and Armour (1992) showed a B response of Sebago potatoes when leaves contained 19 mg B/kg. In a foliar experiment, the Cu concentration in YFEL of poppy at hook stage was above 60 mg/kg when toxicity caused yield reduction. In a basal experiment with carrot, the concentration of Cu in leaves at mid-growth stage was about 8 mg/kg and application of Cu increased the yield, but not the Cu in the leaves.

We did not attempt to tabulate the critical concentration of trace elements in plant tissues, because these concentrations may vary with the plant cultivar, plant part, stage of growth and the interaction of other nutrients. The ranges identified as deficient, adequate and toxic have large overlaps or gaps, depending on the condition of calibration. This information is well reviewed and collated in the book by Reuter and Robinson (1997).

7.4 Nutrient interactions

We observed some highly significant interactions between Cu, Zn, Mo and B concentrations in the YFEL in the poppy experiment. When B, Mo or Zn were omitted from a complete foliar solution containing Cu, the concentration of Cu in YFEL increased by 3-10 fold. In the absence of Mo, B concentration increased, but omission of B reduced the concentration of Mo. These interactions may complicate the use and interpretation of plant analysis.

7.5 Sources and method of application of trace elements

In our experiments, metallic trace elements Zn, Cu and Mn were applied from three sources: mineral, chelates and lignosulfonate. Boron and Mo were used as either in mineral or lignosulfonate forms. The mineral forms of Zn, Cu and Mn, such as sulfate, nitrate and chloride and the complex forms such as chelate and citrate have been used for many decades in Australia and elsewhere. Lignosulfonate trace elements have been shown to be efficient sources of trace elements (Salardini and Murphy 1977 a, b), but are not commonly used in Australia. Attempts were made when possible to compare the latter source of trace elements with either mineral or chelated forms.

Since there were only a few yield responses to the trace elements applied, the comparison of the effectiveness of the sources was only possible by comparing the changes in plant composition. All sources, when applied as foliar spray, were readily absorbed and translocated to other tissues, such as seeds in poppies. When trace elements were applied to soil, the change in tissue concentration was not as pronounced as in the case of foliar use. Band placement, even at lower rate, was more effective than broadcast application.

In most cases the changes in tissue nutrient concentrations from sources applied at similar rates was in order Chelate>Lignate>Mineral. At commercially recommended rates, they all changed the tissue composition significantly. We did not conduct any cost/benefit analysis for trace element sources used, but compared the cost of materials at recommended rates. Although chelates were much more effective than the mineral forms and were recommended at lower rates, they were more expensive per unit weight, and the final cost of application was nearly the same. We could not make similar comparisons for the lignate sources, as they were costom formulated for the individual farmers or us.

We found Zn toxicity and reductions in yield of sweet corn and broccoli when 1 kg Zn/ha or more was broadcast as chelate prior to planting, whereas 0.5 kg Zn/ha from the same source increased the yield. In some foliar trials, Cu and Mo lignate at the producer's recommended rate caused leaf burn and toxicity, whereas Cu sulfate and sodium molybdate were safe even at concentration supplying many fold greater amounts of Cu and Mo than the lignate

7.6 Trace element fertiliser recommendations

This study showed that the use of trace elements in vegetable crops in Tasmania, based on current method of recommendation, goes far above the crop requirement and on occasions may result in levels of trace elements toxic to some crops

The current study showed that the past practice of using trace element fertiliser routinely to reduce the risk of trace element deficiencies would in most cases results be a wasteful action. More over, in some occasions a reduction in yield could have been experienced due to B or Cu toxicity. We also found that a yield or quality response to trace elements was only likely where soil test indicated a deficiency.

Although it is correct that certain crops require more of some trace elements, we do not believe that trace elements be applied to these crops unless soil analysis results identified the need for application. Blanket application of single or multiple trace elements may cause an imbalance of these nutrients in soil, causing toxicity of one or deficiency of others and fail to act as an insurance against probable trace element deficiencies.

Foliar use of trace elements has been an acceptable practice in other states or countries. The practice is based on the fact that a deficiency of a trace element has been confirmed by previous studies including soil and plant analysis, but the correction of the deficiency by soil fertilisation has not been practical or economical for that crop. Conversely in Tasmania, vegetable crops are receiving foliar sprays of trace elements only as an insurance or for the 'just in case' scenario. Much of visual crop improvements gained by foliar use of most of foliar fertilisers are due to the effects of major elements mainly N in the mix. Although the reduction of yield or damage to soil health is not expected by the use of most commercial foliar products, they are more likely to be costly and useless under our conditions.

Most soil analysis laboratories, which provide services to the Tasmanian farmers, are offering reliable soil trace element tests on affordable costs. We strongly recommend that soil test for trace elements be carried out at least once every 3 years, but the interpretation of results should be based on the scales of critical concentrations suggested in the current report (based on Peverill *et al.* 1999).

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9 Publications

The outcomes of the study were presented to vegetable, poppy and associated industries such as fertiliser companies, agricultural consultants, analytical laboratories, seed and seedling companies. The outcomes were decimated in 6 technical seminars, 6 field days, a number of extension talks to farmers and two popular publications. We recommend establishing a new series of activities to extend the outcomes of the project further. Samples of the print materials are given hereafter.

HRDC

The Blue Poppy Syndrome Project

Department of Primary Industry and Fisheries
TASMANIA

1994/95 Progress Report to Poppy Industry Contributors

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9.1 Blue Poppy Syndrome

9.1.1 SUMMARY

In some fields after germination of poppy, the seedlings turn blue or purple and either die or stop growing. The number of dead plants, in some fields, is so great that crop should be abandoned. The problem is known as blue poppy syndrome and was percieved to be a trace element related problem.

The objective of the project were to identify the causes of blue syndrome and to reproduce the field symptoms in the glasshouse.

Six sites showing the incidence of blue syndrome visited at least twice by the research and field officers of DPIF and poppy companies. Detail information including soil and crop condition, paddock history and the location of affected areas were examined and recorded.

Two glasshouse trials conducted. In both trial three levels of P, equivalent to 0, 50 and 200 kg P/ha were incorporated into the soil and two levels of banded P, equivalent to 0 and 20 kg P/ha were employed. After germination, the intensity of blue colour, vigour and height of seedlings were scored.

The results of glasshouse trials indicated that in the absence of banded P, nearly all seedlings grown on nil or even 50 kg incorporated P/ha showed severe purplish colour and had a retarded growth. At 200 kg incorporated P/ha rate the majority of seedlings were healthy but small. When 20 kg P/ha was band-placed, the rate of incorporated P was less important and most seedlings were healthy.

The results of glasshouse work and the field surveys *strongly suggested that the cause of the problem was the low supply of P from soil to seedlings* and it was exacerbated by drought, low temperature, insufficient contact between the seed and soil and loose soil structure.

It was recommended that paddocks lower in soil Colwell P than 40 mg/kg (Olsen P of 8) not be selected for poppies. In soils low in P, bulking the seed with triple superphosphate (low-Cd) is recommended. When sowing in paddocks with a loose soil structure, especially after pasture, a slower speed and the use of press wheels to improve the soil-seed contact is recommended. Soil moisture condition should be kept high enough to insure a good establishment.

9.1.2 INTRODUCTION

In some fields after germination of poppy, the seedlings turn blue or purple and stop growing. Application of herbicides normally applied in one to two weeks after germination, kills these stressed plants. The number of dead plants, in some fields, is so great that crop should be abandoned. In many paddocks, the problem may appear in only some parts of the field and in patches. This problem is called **blue poppy syndrome**.

Blue poppy syndrome occurs 1-2 weeks after germination and the failure in establishment of poppy would be expected if after a week or two of germination a large number of seedlings are purple in colour. Plants in some fields, especially if irrigated or received rain may partially or fully recover. The poppy industry assumed that trace element deficiencies might be the cause of the problem, and supported the Trace Elements Project (PT320) to resolve the problem.

9.1.3 OBJECTIVES

The objective of the project were

1. to identify the causes of blue syndrome
2. to reproduce the field symptoms in the glasshouse

9.1.4 METHODS

Two major methods were employed in identification of causes of syndrome. Field survey of affected paddocks and conducting glasshouse trials to reproduce the symptoms were conducted.

9.1.4.1 Field Surveys

The research and field officers of poppy companies reported any incidence of blue syndrome and the sites were visited and soil, crop, paddock history and the location of affected areas were examined and recorded. The sites were revisited a few days later, especially after a rain or irrigation and changes in plant colour and vigour were recorded.

9.1.4.2 Glasshouse trial

The objective of glasshouse was to reproduce the blue poppy syndrome, and consequently, identify at least one of the factors contributing to the incidence of the problem

In the last year trial, the effect of rate and method of application of P was studied, but due to a fault in the cooling system, the rate of germination was lower than was desired. To be more confident of the finding the glasshouse trial was repeated in the 1994 season.

A soil collected from a paddock under a long-term pasture was used in this trial. The soil analysis is given in Table (1A).

In a completely randomised design experiment with 5 replicates, the effect of 3 rates of incorporated and two rates of band-placed P on the incidence of blue poppy syndrome was studied.

Three levels of P, equivalent to 0, 50 and 200 kg P/ha were mixed with the soil and placed in 600 g aluminium trays. Sufficient P fertiliser and poppy seed were mixed with a batch soil to be able to supply equivalent of 20 kg P/ha and 50 seeds per tray, when 20 g of the mix was added used for each tray. Two bands of the mixture (10 g per band) were placed on the surface of each tray. Similar mixture of soil and seed was also prepared without addition of P and used in another series of trays. After germination, the intensity of blue colour, vigour and height of seedlings were scored. Soil Olsen P was determined at termination of the trial.

Table 1A. Some characteristics of the soil used

pH	EC	Org C	P	K	Cu	Zn	Fe	Mn	B
1:5 H20	dS/m	(%)	mg/kg						
5.5	0.09	6.2	16	145	1.71	1.18	56.4	56.4	1.66

The colour score, calculated as the product of the number and extend of blue syndrome is shown in Figure. (1A). A score of 100 represents the condition when 100% of seedlings were showing severe purplish, while a score of 300 indicates that all of seedling being healthy and green.

9.1.5 RESULTS AND DISCUSSION

9.1.5.1 Field observations in 1993

9.1.5.1.1 East Devonport

Only a small area on a shallow soil located on the north-facing slope was affected. Seedlings in this area were compared with the healthy plants in other parts of paddock. The main difference was found to be the lack of fertiliser delivery, caused by the blockage of the fertiliser applicator. This was exacerbated by dryness of soil, due to the direction of slope and higher evaporation. The seedlings were also smaller than the healthier seedlings in the rest of the paddock. The seedlings recovered significantly a week later after receiving a 10 mm rain.

9.1.5.1.2 Sassafras

Blue seedlings were observed in widespread small patches in the field. The soil, to a depth of 50 to 75 mm, was very dry. The seedbed was coarse and cloddy, probably due to cultivation or drilling in a wet soil. Most of the affected seedlings were not covered by soil and their roots had not entered sufficiently into the soil. Following a rainfall, a small number of seedlings recovered. They were sufficient to maintain an acceptable plant density.

9.1.5.1.3 Elliott

The paddock had been under long term pasture. Soil was loose and bulky. The affected areas were located on the slope. The flat parts of paddock maintained a healthy plant population. A close examination of plant rows showed a very shallow sowing. Judging by the location of the clay particles used for bulking of seed, in the affected area seeds were placed on the surface. After a good rain, the problem was over, and many blue poppy seedlings recovered.

9.1.5.2 Field observations in 1994

Similar visits were made in 1994 as the in the previous year. Fewer affected sites than 1993 season were reported by the advisory officers of poppy companies. Where the symptoms appeared, they were caused by the factors identified in the 1993 report.

9.1.5.3 Glasshouse trial

The results of glasshouse trial indicated that in absence of banded P, nearly all seedlings grown on nil or even 50 kg incorporated P/ha showed sever purplish colour and had a retarded growth. At 200 kg incorporated P/ha rate the majority of seedlings were healthy.When 20 kg P/ha was band-placed, the rate of incorporated P was less important and most seedlings were healthy (Fiqure 3A).

Vegetative scores (Figure 2A) showed that both rate and the method of placement of P fertiliser influenced the seedling development, but the differences were not as large as for the colour score (Figure 1A).

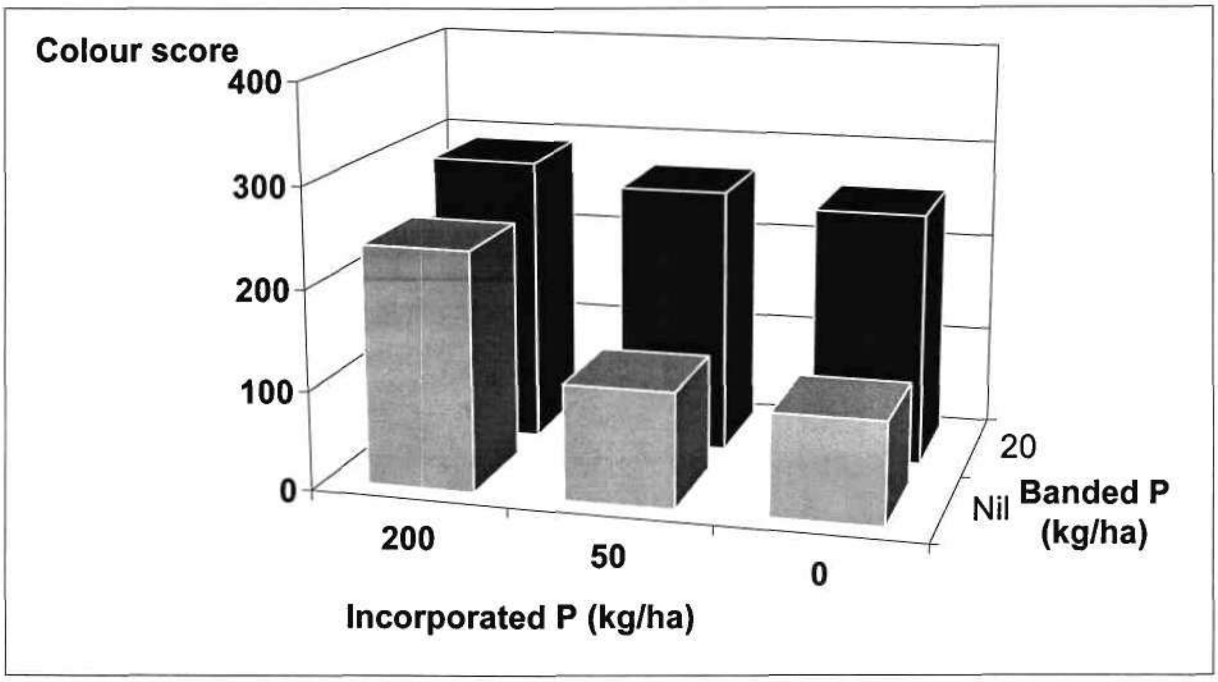

Figure 1A. Effect of banded and incorporated P fertilisers on the seedling colour score

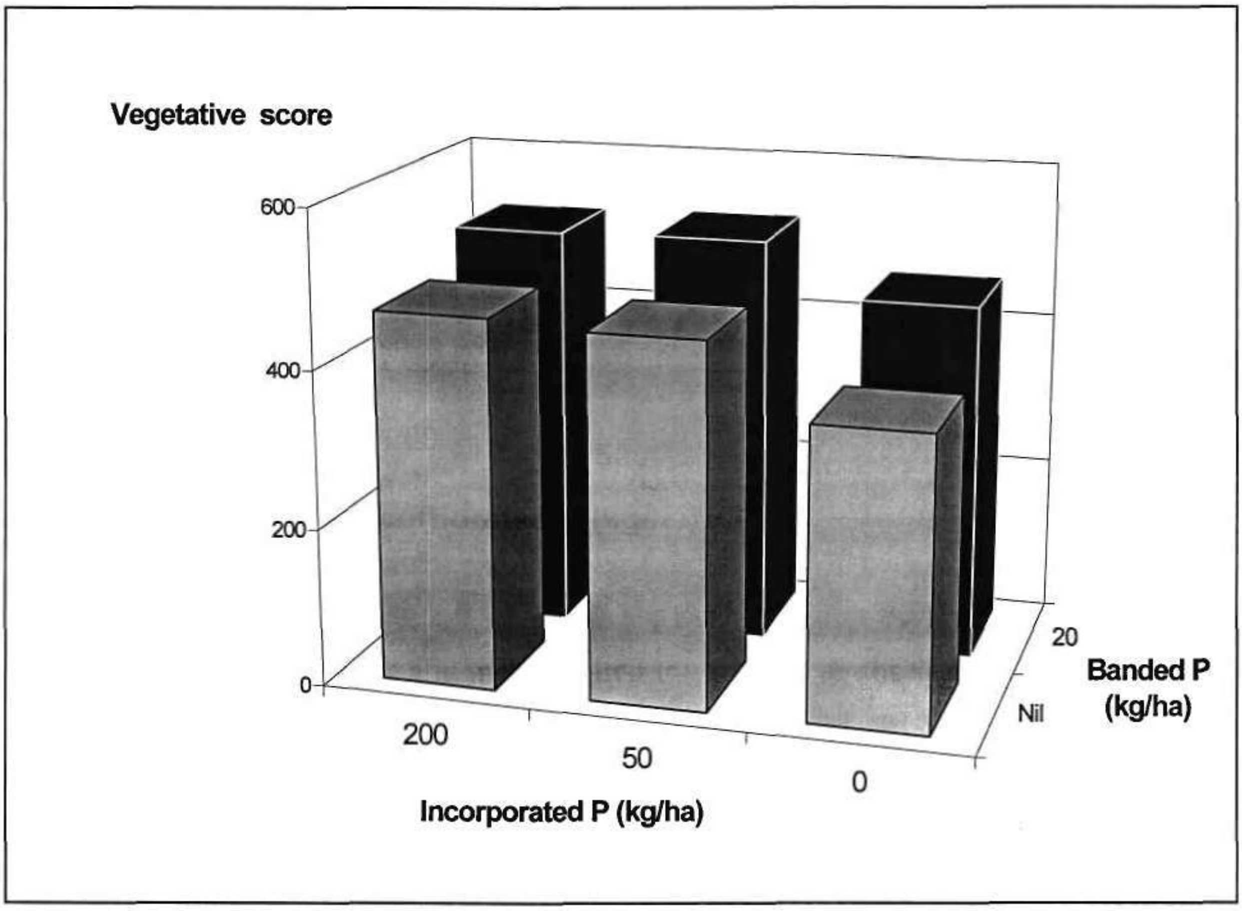

Figure 2A. Effect of banded and incorporated P fertilisers on the vegetative score of the seedlings

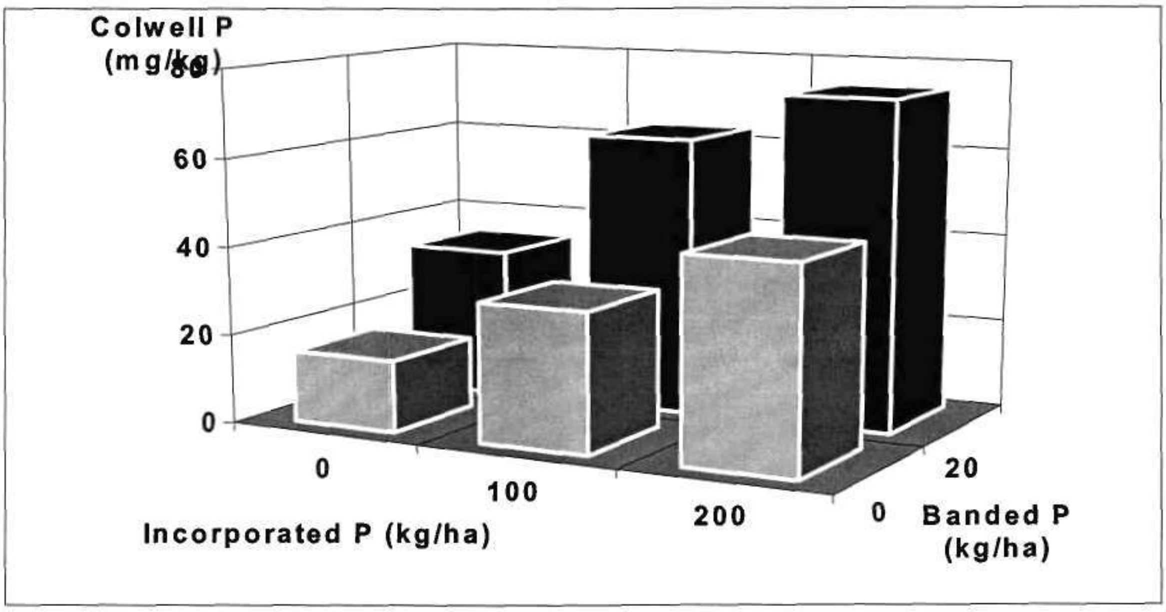

Figure 3A. Effect of banded and applied P on the soil extractable P

9.1.6 CONCLUSIONS

Based on the results of two glasshouse trials and many field observations, discussion with researchers, field officers and growers we concluded that one or more of the following factors were responsible for the incidence of blue poppy syndrome:

1. Incorrect P placement
2. Shallow planting depth
3. Low soil moisture at seedling stage
4. Insufficient soil-seed contact
5. Low soil P

It was also more likely that the syndrome occurred in the following conditions:

6. In paddocks very low in P
7. In paddocks low in soil fertility
8. In paddocks coming out have long term pasture
9. When rainfall is delayed after germination
10. When fertiliser has not been delivered at planting

11. When seedbed is course

12. In paddocks low in pH and high in soluble Al

Based on the information gained from the glasshouse work and the field surveys and the experience of growers and operators, it is *strongly suggested that following factors are the causes of the problem:*

1. Soil P is one of the important factors causing blue syndrome and its effect will be exacerbated by drought, low temperature and insufficient contact between the seed and soil.

2. Transfer of water from soil to seedling is another important factor. A coarse seed bed, shallow planting, and bulky soil structure contribute to both insufficient soil moisture transferee and reduced uptake of P.
3. Soil pH is only important at this stage, if lime super has not been mixed with the seed or its delivery has stopped during sowing.

The following factors are the result of other factors rather than the cause:

1. Aluminium toxicity will be an important factor in pH below 5.0. It is, therefore, less important in many cropped soils. At the early stages of poppy growth when blue syndrome occurs, roots are mainly developed in the topsoil that have a pH of 5.5 or greater. At this pH, the concentration of soluble Al is very low.

2. Frequent incidence of blue poppy syndrome after long term pasture, is the results of combination effects of some or all these factors. Factors such as loose soil structure, low phosphorus low soil-seed contact or low soil pH may be responsible for the blue syndrome in paddocks sown after a long-term pasture.

9.1.7 RECOMMENDATION

1. Soil P would be a critical criterion in selecting sites for poppy. Paddocks lower in soil Colwell P of 40 mg/kg (Olsen P of 8) are likely to experience the blue syndrome problem and are not recommended for poppies.

2. In soils low in P, mixing of seed with lime and super is recommended. Use of triple superphosphate in place of single super is highly recommended, unless you are sure the

single super is low in Cd. Some of commercial single superphosphates add more than 8 times Cd than standard triple super for the same rate of P.

3. Loose soil structure is another major cause of the problem. Paddocks with a loose soil structure, especially after pasture, would have problem in making a suitable soil-seed contact. Sowing in these soils in a slower speed and using a press wheel improves the contact.
4. Soil moisture condition should be appropriate for good establishment. If the sowing is conducted in dry soil, a rain or irrigation is necessary

9.1.8 FUTURE WORK

The objectives of the project have been achieved and further experimental work is not recommended. However, the extension of the results to the industry field officers, operators and contractors needed to be pursued by poppy industry. I would be glad to help if needed.

Trace elements project on the University of Tasmania web site

http://www.tiar.tas.edu.au/domino/tiar/tiar.nsf/framv/frameset_rd

9.2 Trace element requirements of vegetables and poppies in Tasmania-on the University of Tasmania web site

Research Investigator:

Dr Ali Salardini, Dr Leigh Sparrow

Funding:

Horticulture Australia Limited, vegetable processing companies, fertiliser manufacturing companies, poppy industry and TFGA.

Commencement and Completion Date:

Project commenced October 1993, completion date for the field work October 1997, report is due October 2001

9.2.1 Background

Although in excess of $ 800,000 is annually spent on trace element fertilisers for vegetables in Tasmania, there are still frequent reports on trace element deficiencies on vegetables. There has been no reported research in this field in the past half-century and limited work in other States has mainly been on pastures and field crops.

Because of the lack of information relevant to horticulture in Tasmania, growers are often presented with conflicting advice on trace element requirements. They are often encouraged to use the more expensive chelated forms of trace elements, but the benefits of these formulations have not been adequately demonstrated. Recommendations can cost more than $200/ha.

9.2.2 Objectives

This project seeks to develop better trace element fertiliser strategies to maximise production and provide vegetable growers with accurate recommendations through the following topical investigations:

To determine the need for Zn, Cu, B, Mo and Mn in potatoes, brassica crops, carrots, peas, beans and field poppies.

To compare the efficiency of foliar and soil applied trace elements in mineral, chelated or lignated forms.

To evaluate three internationally used Universal extractants: Morgan-Wolf, Mehlich-3 and Ammonium bicarbonate - DTPA, and the recommended method for the single trace element tests, as diagnostic technique.

To examine the usefulness of plant analysis as a diagnostic technique for predicting the trace element requirements of vegetables and field poppies.

To provide vegetable and poppy growers with accurate trace element fertiliser recommendations based on soil and plant analysis.

9.2.3 Work undertaken to date:

During the four years life of the field studies, we completed 12 foliar and 7 basal trace element experiments on the main processing vegetable crops- potatoes (10 sites), cauliflower, broccoli, green peas, green beans, carrots sweet corn and field poppies (Figure 1B).

The sites with the lowest content of one or more of the trace elements were selected after consulting more than 1000 commercial soil analytical results and repeating the sampling and analysis of 60 of the most deficient sites.

The trace elements targeted for investigation in the order of priority were Zn, Cu, B, Mo and Mn. Two or all of the commonly used sources of trace element fertilisers, mineral, chelate and lignate were compared in most trials.

Total and marketable yields, industry quality criteria and soil and plant tissue composition were determined and discussed in all trials.

The outcomes of the study were presented to vegetable, poppy and associated industries such as fertiliser, agricultural consultants, analytical laboratories, seed and seedling companies in 6 technical seminars, four field days, number of extension talks to farmers and two popular publications.

Figure 1B. Glasshouse studies on trace element requirements of poppies

9.2.4 Results to date

9.2.4.1 Yield response

Because of routine application of trace elements in the past two or three decades, most long-established vegetable farms are sufficiently supplied with trace elements. Although we selected sites with the lowest trace element content that we could find, in 171 combinations of treatments resulted from variations in crops, method and rates of application and trace elements, only 9 positive or negative yield or quality responses were observed.

9.2.4.2 *Soil analysis*

This study showed that, when the interpretation criteria presented in the recent Australian "Soil Analysis- an Interpretation Manual" (Peverill *et al.* 1999.) were used, soil analysis gave reasonable predictions of soil trace element status. The predictions were more accurate where crop species and soil type were taken into account. We tabulated the interpretation guides for soil Zn, Cu and B status that could be used more appropriately on vegetable crops in northern Tasmania. We strongly believe that the critical soil trace element concentrations employed by the local fertiliser advisers are many folds greater than the correct values.

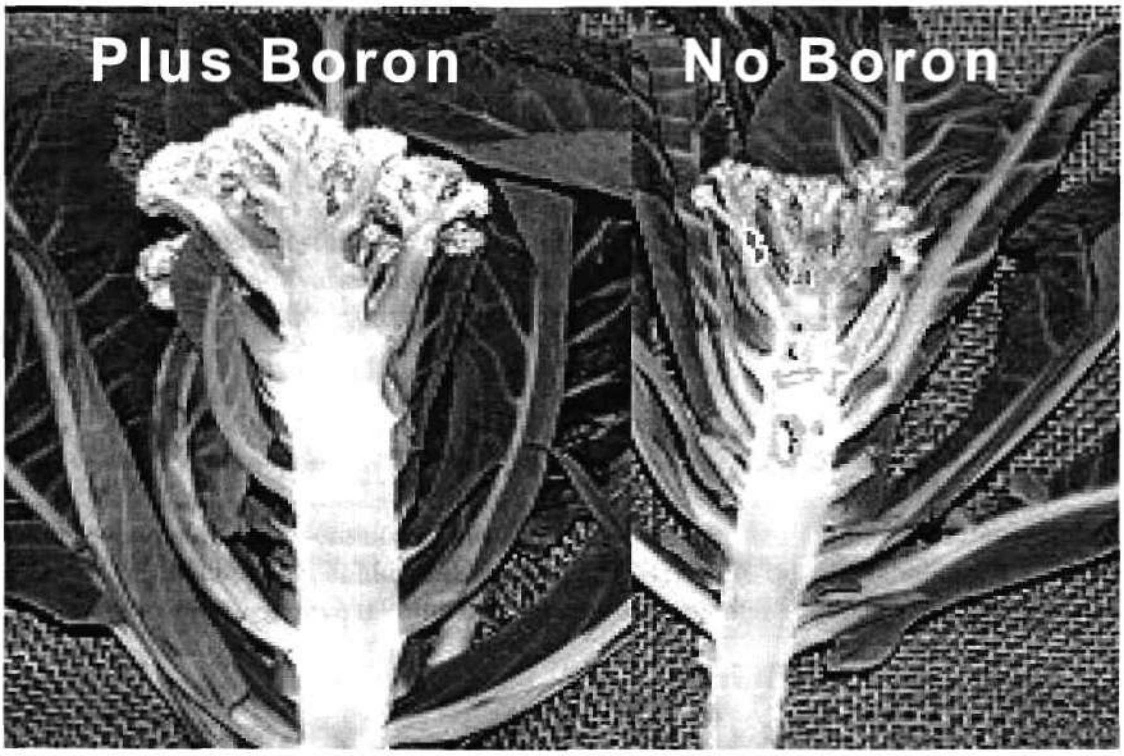

Figure 2B. Boron deficiency on brassica crops was observed more frequently than other trace elements

9.2.4.3 *Plant analysis*

In nearly all experiments, plant analysis results when interpreted using the guidelines reported in the "Plant analysis-an Interpretation Manual (Reuter and Robinson 1997), correctly predicted the response of crop to trace elements. We did not attempt to tabulate the critical concentration of trace element in plant tissues, because these concentrations may vary with the plant species, cultivars and parts, stage of growth and the interaction of other nutrients. We recommend that the plant analysis manual to be consulted for plant analysis interpretation.

9.2.4.4 *Source and methods of application*

All sources, when applied as foliar spray, were readily absorbed and translocated to other tissues, such as seeds in poppies. When these were applied to soil, the change in tissue concentration was not as pronounced as in the case of foliar use. Band placed method, even at lower rate was more effective than broadcast application. The efficiency of sources applied at similar rates were in order of Chelate<Lignate<Mineral. At commercially recommended rates, they were similarly effective and costing the same.

9.2.4.5 Trace element recommendation

We believe that the need for trace elements application to vegetables in Tasmania is grossly over-estimated by most local and visiting farm consultants.

Although it is correct that certain crops require more of some trace elements, [eg. brassica crops need more B (Figure 2B) and Mo], we do not believe that trace elements routinely be applied to these crops unless soil analysis identified a need. This suggestion prevents the probable imbalance of these nutrients in soil, which may cause toxicity of one or deficiency of other trace elements.

In Tasmania, vegetable crops are receiving foliar sprays of trace elements only as an insurance, and not to correct known deficiencies. Much of visual improvements are due to the effects of major elements mainly N in the commercial mixes. Although the reduction of yield or damage to soil health is not expected by the use of most commercial foliar products, they are more likely to be costly and useless under our conditions, unless are used to correct a known deficiency.

9.2.5 Technology transfer

The outcomes of the study were presented to vegetable, poppy and associated industries such as fertiliser companies, agricultural consultants, analytical laboratories, seed and seedling companies. The outcomes were decimated in 6 technical seminars, 6 field days, a number of extension talks to farmers and two popular publications. We recommend establishing a new series of activities to extend the outcomes of the project further.

9.2.6 Acknowledgments

We acknowledge the financial support of Tasmanian Farmers and Grazier Association, Simplot, McCain, Tasmanian Alkaloids, GlaxoWelcome, Pivot Agriculture, Impact Fertilizers and Serve-Ag.

9.2.7 References

Peverill, K. I., Sparrow, L. A. and Reuter D. .J. (1999). "Soil Analysis, an Interpretation Manual (CSIRO Publishing, Collingwood Victoria, Australia).

Reuter, D. J. and Robinson, J. B. (Editors). (1997). "Plant Analysis, an Interpretation Manual". (CSIRO Publishing, Collingwood Victoria, Australia).

This article was presented in many courses held throughout Tasmania in the Whole Farm Planning program organized by by Department of Primary Industry, September 1994.

9.3 DIAGNOSIS OF TRACE ELEMENT DEFICIENCIES WITH REFERENCES TO TASMANIA

Ali A Salardini

Vegetables and Allied Crops Branch

Department of Primary Industry

9.3.1 Summary

Different tmethods of diagnosis for trace element status of soil and plants are reviewed. Information essential to the most effective use of these methods for determining the fertiliser needs of crops are briefly discussed. The major problem with recommendation of trace element fertilisers in Tasmania is the lack of scientific information in the field of trace elements and the use of diverse diagnostic methods with doubtful reliability. It is suggested that a discussion group consisting of parties involved should examine the present Tasmanian situation and means of improving fertiliser recommendations by encouraging a unified approach to the problem.

9.3.2 Need for trace element application

Amongst many trace elements that are essential for a normal growth of plants and animals only a few may be of concern in Tasmanian agriculture. Soils are generally capable of supplying the required amounts of trace elements to plants and consequently to the animals.

In certain circumstances, it is essential to supplement the trace elements provided by soil.

A. Certain crops naturally need more of some trace elements than others. Brassica plants require a larger amount of boron (B) and molybdenum (Mo) and legumes including legume pastures, beans and peas need a good supply of Mo. Plants with a latex system like poppies and lettuces have the highest requirements for B. In contrast plants of grass family, eg, pasture grasses, oats and sweet corn may be successfully grown in low B soils.

B. Some soils contain less of some trace elements because they are developed from the parent material low in those elements. Sandy soils and red soils developed from basalt especially when acidic are generally low in B and Mo. Neutral alluvial soils and soils with high organic matter contain greater amounts of these trace elements in available forms.

C. Soil conditions and management practices would influence the availability of trace elements to plants. Application of lime to an acid soil improves the availability of Mo. Excessive use of lime may lead to copper (Cu), cobalt (Co), iron (Fe) and/or manganese (Mn) deficiencies in plant and animals. Excessive application of phosphate fertilisers, especially high analysis mixes reduce zinc (Zn), Cu and Mo availability to plants.

9.3.3 Trace element deficiencies in Tasmania

An annotated list of plant diseases including trace elements disorders has been compiled by the Department of Primary Industry Tasmania (Sampson and Walker 1982). There are 40 references to the problems related to the trace element disorders in pasture, field and horticultural plants in Tasmania since 1935. Except in a handful, only the incidence of deficiency of B, Cu, Mn, Mo and Zn and the toxicity of Mn have been reported and no experimental results has been produced.

Molybdenum deficiency was examined in more detail by Fricke (1943,1944,1945) and Wade (1949). The problem of B deficiency in apple trees was discussed by Carne and Martin (1937). The response of poppies to B applications was examined by Laughlin (1980) in glasshouse and field experiments. Routine or periodic applications of Mo containing fertilisers to brassica crops, beans and peas and borax to poppies, brassica crops and fruit trees are now an accepted practice. This is based on the results of research from other states or countries or the individual experiences.

Iodine, selenium (Se), Co and Cu deficiencies in farm animals are wide spread in Tasmania, but more frequently observed in areas of high rainfall with light textured acid soils (Campbell and Pitt 1988). Trace element deficiency in pasture plants is rare except Mo deficiency (Paton 1956) that is corrected by routing application of molybdate superphosphate.

In recent years, there has been a large increase in recommendation and use of trace elements to pastures and crops in Tasmania. These recommendations, besides Mo and B, are covering a list of trace elements. These elements are Zn, Cu, Se and Co that were assumed either sufficiently supplied by the soil or in the grazing situation could be prescribed for direct animal treatment. In some recommendations, the use of special trace element compounds has been advised. Whether the new compounds are more effective than the usual forms, has not been examined under our conditions but they are certainly more expensive.

The reason we are not able to come to a quick and fair judgement on the accuracy of these recommendations lies in the complexity of the diagnostic techniques. This subject is here been dealt with.

9.3.4 Diagnostic Techniques

Trace element deficiencies may be recognised by examining the visual symptoms or the results of soil or plant analysis.

9.3.4.1 Visual symptoms

Usually when the symptom of trace element deficiency appears the damage to the crop has already been inflicted and it is too late to correct the shortage. This method of diagnosis however may provide the clues to the causes of deficiency. The causes may include inadequacy or low availability of the element in the soil, too acid soil, over application of water, lime or fertilisers. This information may be used to prevent the incidence of deficiency in the future.

9.3.4.2 Diagnostic tests

Plant nutrient requirements can be identified by separate or combined soil and plant tissue tests. These tests are used to determine that nutrients are outside normal limit in soil and plant tissues. To attain a maximum benefit in application of these tests 3 stages must be considered: A. selection of suitable test, B. calibration of the test against crops responses and estimating the critical level that separates the deficiency from adequacy, C. interpretation of the results and recommendation. These stages will be discussed later.

9.3.4.3 Plant tissue tests

As a rule a young mature leaf, in another word the youngest fully expanded leaf (YFEL) is selected for most crops. The petiole or the mid-rib is generally selected for evaluating the status of nitrogen, potassium and phosphorus but whole leaf or blade (lamina) is preferable for trace elements.

Plant tissue test for pastures may be used to examine the trace element status of plants regarding herbage production. This technique is not as effective in examining the trace element disorders in livestock. For the latter additional animal tissue testing and treatment of animals directly is recommended (Egan 1975).

Plant tissue test is not always suitable for identifying the need of trace element of the current crop. Unless it is performed in early stages of growth and a proper calibration is available for that physiological stage of growth.

The analysis of dry plant tissues (plant test) is highly recommendable for the major and trace elements. The sap test has successfully been used for the major elements. The confidence in plant tissue test has been obtained by examining the results of hundred of thousand of samples analysed annually in research laboratories all over the world. In contrast, the use of sap test for assessing trace element status is still in its rudimentary stage Table (1C).

Correct application of plant tissue testing, as a diagnostic technique is much more complex than it first appears to be. In contrast to soil test, the selection of test is simple but sampling plant tissue is a very delicate affair. The concentration of trace elements decreases significantly with plant age, it is different at different plant parts and may be influenced by change in concentration of other nutrients (Reuter 1975, Smith 1986). Plant tissue testing should be related to specific stages of plant development, to specific plant part or tissue and specified plant species or even cultivars (Jones 1972). Without knowledge of critical concentrations that gives the limits of deficiency, sufficiency and toxicity plant tests are useless. The advantage of plant test over soil test is that these values may be obtained from the works conducted in different parts of the world on the same plant. Generally, there will be little concern about the effects of regional soil and environmental differences on the critical concentrations.

The interpretation of the results of plant tissue tests although simpler than that of soil tests requires some knowledge of nutrient interactions in the plant. A low zinc in plant tissue may not often be due to a low soil zinc availability but to an excessive application of phosphate. Low boron in plant may have been caused by high application of nitrogen, lime or even potassium fertilisers. In both cases, recommendation of trace elements is not the correct solution.

9.3.4.4 Soil tests

The major advantage of soil test over plant test is in its ability, when suitably selected and performed, to indicate the need for trace element application at sowing time. The number of soil samples analysed in the U.S.A. is nearly 8 times greater than that of plant samples (Peck 1990, Jones 1972). Most of soil and plant samples are analysed for both the major and trace elements. That is why in the United States the recommendation of trace elements still relies

Table 1C. Concentration of important elements in some field and horticultural crops (mg/kg dry matter)[1]

Crop	Stage of growth	B		Cu		Mn		MO		Zn	
		Critical	Adeq.	Critical	Adeq.	Critical	Adeq.	Critical	Adeq.	Critical	Adeq.
Bean	Bud	15	40-60	3-5	5-15	25	30-300	0.01	*0.4*	20	30-60
Broccoli	Heading	20	30-50	0.5	1-5	20	30-200	0.01	0.4	20	45-100
Brussel sprout	Budding	10	30-100	-	-	-	80-150	0.01	0.1-0.7	15	20-80
Capsicum	Early fruit	15	40-100	5	10-200	20	25-300	-	-	-	35-350
Onion	Mid-growth	20	25-45	3	5-10	40	55-70	-	-	-	20-180
Pea	Early flower	20	25-60	-	5-10	-	45-100	-	-	-	40-50
Potato	Early flower	15	20-50	3	5-10	20	40-300	0.08	0.1-1.5	10	15-30
Sweet corn	Silking	-	50-70	5	8-12	-	20-50	0.08	0.2	15	20-40
Tomato	Early flower	10	30-100	5	8-15	25	50-500	0.1	0.6	20	30-200
Oats	In boot	3	6-15	2.5	3.3-5	15	30-100	-	0.2-0.3	15	20-70
Soybean	Early flower	10	20-100	-	6-15	20	30-200	0.12	0.5-6	15	25-80
Wheat	In boot	5	6-10	1.6	2-5	15	40-100	0.05	0.1-0.2	10	15-17
Clover	Pre flower	20	25-30	*4*	5-7	20	25-30	0.1	0.15-0.2	12	16-20
Ryegrass	Pre flower	3	5-15	*4*	5-12	-	50-300	0.15	0.3-0.4	10	15-20
Apple	January	15	20-40	*4*	6-20	20	50-100	-	-	10	20-50
Cherry	January	15	20-60	3	5-16	20	40-150	-	-	15	20-50
Grapevine	Flowering	20	30-100	3	6-16	20	25-		-	15	25-50
Azalea	On flower	15	20-100	5	6-15	30	30-300	0.1	0.1-1	15	20-100
Carnation	Pre flower	20	30-100	2	4-20	30	80-300	0.3	1-5	15	25-75
Chrysanthemum	Pre flower	20	25-200	5	10-15	20	50-300	-	0.3	10	40-100
Rose	Early flower	30	30-60	5	5-15	30	30-250		-	15	15-50

[1] Compiled mainly from Reuter and Robinson (1986) with additions from own work and many other sources.

The plant tissue employed in most crops has been the whole youngest fully expanded leaf (YFEL).

heavily on soil analysis. To increase the usefulness of soil test, an appropriate soil test should be selected with regards to regional soil and climatic characteristics. The interpretation of theresults must be based on research studies calibrating the test with crop response to addition of trace elements in similar soil and plant conditions.

There are many methods for the extraction of available forms of trace elements from soils. Some of these methods are specifically developed to be used for one or two trace elements and others are designed to evaluate the status of several elements in the soil (Cox and Kamprath 1972). In an ideal situation, a universal extractant suitable for estimating the availability of most trace elements may be found. Table (2C) shows the most widely used extractant for testing trace elements in the U.S.A., U.K., Canada and Australia. Since more than 3.3 million soil samples are analysed annually in research and commercial laboratories in the U.S.A. (Peck 1991) more emphasis is placed on the methods adopted in that country.

9.3.4.5 Universal soil extractant

The term 'universal soil extractant' is used to designate a single extractant that can be used to extract most of major and trace elements. The advantage of universal extractants in reducing time and cost of soil analysis is considerable. The extract is normally used for multi-element analysis by ICP spectrometers and autoanalysers.

The first universal soil extractant was developed by Morgan (1935) in Connecticut Experimental Station in the U.S.A. and was quickly accepted by most states and other countries. This extractant and its modified forms have been frequently used by commercial laboratories in many countries until late 1950's. Morgan solution is in little use today (Jones 1990) and has been replaced by the more reliable extractants. In most soil and plant test, services in the U.S.A. one or two of the six universal extractant reported in Table (3C) are employed to diagnose the soil trace elements status.

The confidence on reliability of trace element soil tests is not as strong as for the major element tests. From a grower or consultant's standpoints, if the trace element status of a field is not known, a soil test will nearly always be better than guessing or waiting to see the symptom of a deficiency. Plant analysis alone may not serve the purpose due to differences between the plants and the influence of temporary factors including weather conditions and fertiliser application.

Trace element tests have their limitations. No plant test or chemical soil test can perfectly reflect or simulate the conditions that exist in the soil during the whole period of crop growth. Thus, the influence of weather, plant density, availability of other nutrients and management factors must also influence the interpretations. Sometimes the results of both soil and plant analysis in necessary to reach a conclusive result.

9.3.4.6 Correlation and calibration

The results of soil and plant test for major and trace elements are useless without existence of a proven relationship between the test values and response of crop to application of fertilisers. The advantage of selecting a well-examined method is that a large body of information is available on their suitability for different crops and under different climatic and soil conditions. This information provides a sound basis for a correct interpretation and recommendation.

To date, only few studies on yield responses of crops to the application of major nutrients have been performed in Tasmania and even fewer have been published. Roberts (1989) has summarised the calibration studies for grazed pastures. Thorp and Wallace (1987) introduce a fertiliser model for predicting potato yield. Chapman (1990) compiled the recent work of the DPIF staff on N, P and K requirements of vegetable crops. For the trace elements in the past, half a century there have been a few reports from the observational field trials but nearly none from the experimental investigations.

Although acquisition of this information is a very expensive and time-consuming undertaking, it is essential that at least for the more important trace elements some experimental evaluations be initiated.

Table 2C. The most widely used extractants for assessment of soil micronutrient status[A].

Element	Method	Soil group	Interacting factor	Predictive value
B	Hot water	All types	Texture, pH,	Excellent
	AB-DTPA	Calcareous	OM,	Good
	Acid	Acid soils	pH, OM	Poor
			None	
Cu	DTPA	Calcareous	None	Acceptable
	DTPA	All type	pH	Good
	Mehlich 1	Acid soils	None	Good
	Mehlich 3	Acid soils	None	Very good
Zn	DTPA	Calcareous	None	Good
	DTPA	Acid	pH, lime	Very good
	0.1 n hcl	Acid	None	Very good
	Mehlich 1	Acid	None	Very good
	Mehlich 3	Acid	None	Excellent
Mn	DTPA	All type	None	Poor
	DTPA	Calcareous	pH	Good
	Mehlich 1	Acid	pH	Good
	Mehlich 3	Acid	pH	Excellent
MO	Acid	All type	None	Poor
	ammoninum		pH	Good
	oxoiate			

A compiled mainly from Peck (1990), Jones (1990) and Sims (1989).

9.3.4.7 *Diagnostic services in Tasmania*

In Tasmania, the lack of information has lead to a situation in which some soil and plant analysis laboratories or consulting companies have adopted the diagnostic techniques that best suited their conditions. Sometimes the techniques are not suitable at all or the use of some techniques has been pushed beyond their capacity or validity. The calibration scales used are arbitrary and little adjustment is made for the variations in soil and regional conditions. In some occasions, one gets the impression that the diagnostic services are used to seduce growers into purchase of unneeded fertilisers. For the trace element tests, the problem is even more serious and incorrect recommendations and large financial losses to growers have recently been reported.

There are several diagnostic techniques for predicting the trace element requirements of crops and pasture that have successfully been employed in some countries. In Tasmania a correct recommendation encounters major problems:

1. Nearly no diagnostic technique has been scientifically evaluated to recommend trace elements application to crops and pastures.
2. Validity of existing methods employed by some consultants is doubtful.
3. Interpretations of the results of soil and plant analysis are generally based on the knowledge of the individuals rather than following a uniform guideline.
4. The confidence of growers on the value of this service is not at its optimum level due to the lack of a unified approach of parties involved.

Table 3C. Information on the widely adopted universal extractants in the U.S.A. compiled mainly from Peck (1990), Jones (1990) and Sims (1989).

Extractant[A]	Soil group	Elements	Status today
1. Morgan (1 935) 0.73M sodium acetate p H 4.8	All acid Soil Pot mixes	P, K, Ca, Mg, Cu, Fe, Mn, Zn, NO_3, NH4, SO_4, Al, As,Hg, Pb	Abandoned
2. Morgan-Wolf (Wolf 1983) Morgan reagent- 0.001m DTPA	All acid soils Organic soils	P, K, Ca, Mg, B, Cu, Fe, Mn, Zn, Al, NO_3, NH_4	Frequently used
3. Mehlich No. 1 (Mehlich 1954) 0.05N HCI + 0.025N H_2S0_4	Acid sandy soils	P, K, Ca, Mg, Na, Mn, Zn	Used in coastal sandy
4. Mehlich No. 3 (Mehlich 1954) 0.2N acetic acid + 0.25N (ammoninium nitrate+ 0.001 M EDTA, pH 2.5	All acid and neutral soils, Soilless mixes	P, K, Ca, Mg, Na, B, Cu, Fe, Mn, Zn	It is replacing most other extractants for acid soils
5. AB-DTPA (Soltanpour and Workman 1979) 1M ammonium bicarbonate + 0.005M DTPA pH 7.6	Alkaline soils	P, K, Na, Cu, Fe, Mn Zn, As, Cd, NO_3	Only method widely used for alkaline soils
6. DTPA (Linsay and Norwell 1978) 0.005 M DTPA+ 0.01M $CaCl_2$ + 0.1M TEA, pH 7.3	Alkaline soils	Cu, Fe, Mn, Zn in alkaline soils	Widely adopted

^A^Computer programs for making lime and fertiliser recommendations based on the results of soil test for and crops are available for extractant 2 and 5.1.

There is no quick or cheap solution to all the problems mentioned above. I hope that we would be able to reach an acceptable approach in solving these problems by exchanging views and sharing experiences.

I suggest that the Department of Primary Industry initiate a discussion group from the representatives of the parties involved to examine the problem and search for the solutions. This group should include consulting and soil and plant testing services, fertiliser manufacturers, farmers and graziers associations and the DPIF to examine the problems and search for the solutions.

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This article was presented in many courses held throughout Tasmania in the Whole Farm Planning program organized by by Department of Primary Industry, September 1994.

9.4 Boron for vegetables

Ali Salardini

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9.4.1 Introduction

To achieve high yields and good quality in our vegetable production, vegetables or any crop should receive balance nutrients composed of major and trace elements. Major elements, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur, are provided by application of mixed fertilisers, lime and dolomite. Trace elements, boron, zinc, copper, manganese and molybdenum are also essential to crops, but are needed, relative to major elements, only in small amounts. Boron is one of the more important trace elements to our vegetable production. Many of you, when growing brassica crops, celery or poppy have used boron fertilisers to correct or prevent boron deficiency. This article answers most of the fundamental questions and provides further information for those who like to know a little more about boron.

The main function of Boron (Chemical symbol B) in plant is related to the growth of root and shoot apical tissues, fruit formation and development, and cell division. That is why B deficiency causes serious reduction in yield and crop quality.

9.4.2 Are crops different in their B requirements?

As regards the B requirements, there is a considerable difference between crops. The usual concentration of B in plants, in most cases, is relative to their need. Table (1D) shows the B demands and B concentration in dried leaves of commercially grown crops in Tasmania. As many growers, besides vegetables, are involved with other crops, this table would help them in knowing B requirements of other enterprises.

9.4.3 What are the symptoms of boron deficiency?

When B deficiency is mild, although yield and quality would deteriorate, no visual symptoms would appear on plant. We call this a hidden deficiency. The symptoms are only visible when there is an acute B deficiency. Only plant analysis can reveal both a hidden and acute deficiency. The symptoms of B deficiency varies in different crops and are describe for some of the vegetables in this article. Please contact us if you would like to know the symptoms on others. As you may notice, in some vegetables, like brassica crops and poppies, the symptom are easily recognised, while in others like beans it could be mistaken with other deficiencies and other information, including soil and plant analysis results may be necessary.

In Brussels sprouts the first sign of boron deficiency is appearance of swellings on the stem and petioles which later become suberised. The leaves are curled and the midribs wrinkled, and older leaves fall prematurely. The stem branches at the top end and the stem pith would be hollow and discoloured. The sprouts are too few, small and loose.

Table 1D. Boron demand of crops and the concentration of B in their dried leaf (mg/kg)

High B-demanding crops	**B Conc.**	**Medium B-demanding crops**	**B Conc.**	**Low B-demanding crops**	**B Conc.**
Vegetables					
Beetroot	60 - 80	Beans	20 - 40		
Broccoli	40 - 60	Carrots	20 - 30		
Brussels sprouts	30 - 40	Lettuce	25 - 30		
Cabbage	40 - 60	Onion	20 - 40		
Cauliflower	30 - 40	Peas	20 - 30		
Capsicum	40 - 60	Potato	20 - 40		
Celery	30 - 60				
Sweet corn	40 - 60				
Tomato	40 - 80				
Field crops					
Lupin	50 - 60	Field beans	20 - 30	Barley	5 - 10
		Maize	10 - 20	Oats	2 - 10
				Wheat	5 - 10
Fodder and pasture plants					
Turnip	40 - 50	Clovers	25 - 30	Oats	5 - 15
Lucern	30 - 40			Phalaris	5 - 10
				Rye grass	5 - 10
Ornamentals					
Carnations	30 - 60	Azalea	15 - 25		
Rose	30 - 60				
Geranium	30 - 60				
Fruits					
Apple	30 - 50	Cherries	20 - 30	Peach	10 - 20
Strawberry	50 - 100	Plums	20 - 30		
Vine	30 - 50				
Others					
Poppy	90 - 120				

The characteristic symptom of B deficiency in celery, lettuce and Chinese cabbage is the cracking of upper surface of midribs and petioles which will later turn brown

In severe B deficiency, poppy plants are thin and stunned, leaves are rolled upward and lamina becomes chlorotic between the veins. Growing points die and flower formation drastically reduced. In less severe B deficiency, plant appearance is normal, except for some stems that may be twisted and capsules are deformed. A part of capsule wall turn yellow and later brown, and stops growing. The growth of other parts forces the capsules to bend to one side. Under the damaged wall, tissues and seeds are damaged, gummy and turn light brown to black. Yield of capsule and seed, and morphine concentration decreases even with mild B deficiency.

The symptoms of boron deficiency on beetroot turnip, sewed and most other root crops are the development of internal black or brown spots and hollow area. When these zones occur at beet surface, disease organisms may enter and canker may develop. These disorders render the roots unmarketable.

Beans are both sensitive to B deficiency and toxicity. Boron deficient plants are stunned, compact and produce several lateral shoots at the base of stem. Growing points are shrivelled and may blacken and die. Flower buds are compressed together and may be shed without opening. Pods are small and twisted.

9.4.4 Where and when B deficiency may occur?

Boron deficiency is most likely to occur in light textured and sandy soils in high rainfall area. This will includes most of sandy coastal soils in northern Tasmania. Another likely condition for the occurrence of B deficiency is the acid soils with naturally low B parent material. This will cover most krasnozem soils in north and northwest Tasmania. Some krasnozem soils are high in organic matter and B release from organic matter could supply sufficient B to a low to medium B-demanding crop, but not to the high B-demanding crops.

When soil is very low in B nearly all crops and in most conditions develop B deficiency, but if B deficiency is mild, other factors including the need of crop, liming, nitrogen fertiliser and soil moisture may influence the extent of damage to the crops. These factors have little or no effect on B supply to crop if soil was supplied with sufficient B.

In soils with marginal B availability low or medium B-demanding crops like cereal grains, peas, carrots and onion may find enough B to get them through the season without a serious deficiency damage. However, the yield and quality of brassica crops, celery and poppy in these soils would suffer.

Liming induces boron deficiency on most crops in medium-B soils. We have frequently seen this problem in poppy crops in red soils of northern Tasmania. It is also possible that by liming hidden B deficiencies had occurred with other crops and had not been recognised. It is essential to apply B to even medium B-demanding crops if lime has been applied recently.

High rates of nitrogen may also cause B deficiency. Growers in northern Tasmania have experienced this with poppy, brassica crops and celery. In some instances high K and P fertilisers may induce B deficiency, but not as commonly as with the N fertilisers.

Delay in rain or irrigation could also increase the chance of boron deficiency in high B-demanding crops. Although supply of water may correct the deficiency, but some damage has certainly been inflicted.

9.4.5 Are there tests to identify or predict the B needs?

Yes there are. There are B soil tests which determine the soil available B. The results of soil test together with the knowledge of the paddock history in relation to lime and B applications can predict the need of B for the crop that you intend to grow. If the results of plant analysis of current crop is available and showed to be low in B, you would be certain that next crop need B application.

Plant analysis for B is an efficient way of knowing whether you should apply B to the current crop as post-emergence treatment. Plant analysis is normally done automatically and the concentrations of a range of elements are reported. The results is, therefore, may be used to identify the need for other nutrients. When recommendation of fertilisers are based on pre-planting soil results and paddock history, there will, normally, be no need for plant analysis.

The methods of soil and plant analysis vary with different laboratories and the interpretation of results depends on the method used and soil characteristics. The recommendation of B based on soil and plant analysis is therefore requires further information and it is best left to experts and the consultants, who provide the service.

Table 2D. Single and mixed B fertilisers marketed in Tasmania

Material	Mode of use in order of preference	B %	kg of material needed for 1 kg B
Borax	Soil and foliar	11.3	8.9
Boric acid	Soil and foliar	17.5	5.7
Solubor®	Foliar and soil	20.5	4.9
B in mixed solid fertilisers	Soil	Varies	-
B in mixed liquid fertilisers	Foliar and soil	Varies	-
B fertiliser in liquid form	Foliar and soil	Varies	-

9.4.6 What B fertilisers are available?

Several B fertilisers are marketed in Tasmania and could be used to prevent or cure boron deficiency. Although B fertilisers are marketed under different trade names, they contain one of the first three materials shown in Table (2D).

9.4.7 How B fertilisers are applied?

The amounts of B fertilisers applied are usually less than 20 kg/ha and would be difficult to be spread uniformly. If there are hot spots after spreading B fertiliser, plants may be burnt or even die of B toxicity in those spots. It is recommended to apply your B fertiliser in one of following ways to prevent plant injury. Boron fertilisers are compatible with most liquid and solid mixed fertilisers:

1. Mix B fertiliser with NPK solid fertilisers and band-place or broadcast the mixture. Some companies custom formulate fertilisers at your request.

2. Mix B fertiliser with N fertiliser and top-dress the crop.

3. Dissolve B fertiliser in water, alone or as an addition to soluble or liquid NPK fertilisers, and spray to the foliage or to the soil.

4. Use liquid B fertiliser for foliar or soil spray or aerial application (if recommended on the package).

9.4.8 Could B fertilisers be mixed with pesticides sprays?

As crops are frequently sprayed with pesticides (includes herbicides, insecticides and fungicides) it would be cheaper and more convenient if B fertilisers could be mixed with them and applied in one operation. To be on the safe side, always follow the instruction given on the label or test the compatibility of B fertilisers with the intended pesticide sprays in advance. Boron fertilisers may be safely mixed with liquid and foliar fertilisers.

Solubor® is designed primarily for spray application and can be mixed with nearly all pesticides, and you could contact the supplier to get the list of spray chemicals compatible with it.

Borax is an alkaline chemical and is **not compatible** with most pesticides. Use borax solution alone or test its compatibility before mixing. Borax may be mixed with liquid fertilisers.

Boric acid is placed between the two and is compatible with many pesticides, but still it is better checking it in advance. For other B foliar fertilisers follow the label instruction or test the compatibility.

9.4.9 What rates should be applied?

The amounts of B fertiliser depend on method of application and the demand of crop. Using B less than lower rate mentioned in Table (3D) normally have little or no effect on correcting or preventing B deficiency. The lower rates in the Table (3D) are for crops with medium B demand. The higher rates are for high demanding vegetables. Half the lower rate is applied to low B-demanding crops. For foliar application, dissolve the recommended amounts in 300 - 500 litres of water add the recommended rate of surfactant (usually 0.5 - 1 in 1000) and spray until it drips from plants. Foliar application may be repeated fortnightly up to 3 times.

Table 3D. The rates of common B fertilisers applied to vegetables

Fertiliser	**Pre-planting**		**Post-planting**	
	Broadcast	**Band-placed**	**Top-dressed**	**Foliar**
Borax	10 - 20	5 - 10	5 - 10	1 - 2
Boric acid	7.5 - 15	3 - 8	3 - 8	0.5 - 1
Solubor®	5 - 10	2.5 - 5	2.5 - 5	0.25 - 1
Others	Follow the instruction on the label			

Pre-planting application of B may be combined with herbicide applications. Solubor® may be added to the tank at up to 7% and spray the soil. Other B fertilisers may also be used in the same way, but their solubility may be a problem for low volume sprays.

If during your crop rotation you apply equivalent of 10 - 20 kg borax to brassica crops or poppy, the soil B would be kept sufficiently high to provide enough B to other crops in the rotation.

9.4.10 Do you like to know more about B?

Please contact Dr Ali Salardini, Senior Research Fellow, Soils and Plant Nutrition, Tasmanian Institute of Agricultural Research (TIAR),University of Tasmania, New Town Laboratories,13 St Johns Avenue, New Town, Tasmania, Australia 7008, Telephone: 03 6233 7638, 0417 385 576, Fax: 03 6233 6145, Another E-mail: ali.salardini@utas.edu.au/,

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9.5 Plant testing, Is there Anything in it for You?

By Ali Salardini

When plants suffer from a shortage, excess or imbalance of nutrients their tissue chemical composition would be affected. That is why when your crop doesn't perform well enough, plant tests are suggested as diagnostic tools. If fertiliser recommendations were based on the results of soil analysis and paddock history, plant tests would rarely be needed. There are occasions; of course, those plant tests could be very useful in the diagnosis of deficiencies and fertiliser recommendation:

When through the fault of our own or not, we have a problem and we would like to know whether that is related to plant nutrition, especially in the case of **trace element** deficiencies.

Soil nitrogen and nitrogen fertilisers, in all soil types, and potassium in sandier soils, could be easily leached out of plant reach by rain or over-irrigation. With plant test we would be able to predict whether there is a need for top-dressing of these fertilisers.

Plant tests can also tell us about the nutrient reserve in the soil and can help us in our fertiliser recommendations to the current and succeeding crops.

There are two types of plant tests: plant analysis and sap test. In plant analysis, certain part of plant is sampled, dried, ground, ashed and analysed for different elements. While for sap test the sap is expressed from plant tissue and directly used for analysis.

To be able to make a good recommendation by sap test or plant analysis the test results should be compared with critical levels. The critical level of nutrients for plant analysis has been worked out nationally and internationally and the method is efficient and reliable, but the turnaround time may be up to two weeks. For some crops this is too long.

For the sap test the critical levels have also been worked out for nitrogen and to a lesser extend for potassium internationally and adapted by the DPIF and Serve-Ag for Tasmania. Sap test can, therefore, be used efficiently for nitrogen and potassium, with turnaround time of 1 or 2 days. Serve-Ag is also using sap test for phosphorus and **trace elements**. Their method has been developed by comparing the results of many tests that they have done for the growers. Although the sap test for P and **trace elements** can be used as a general guide, they are yet to be improved for accurate diagnoses.

The results of both sap test and plant analysis are affected by time of sampling, environmental conditions and plant growth stage. Interpretation of plant tests and fertiliser recommendations should take the sampling method, paddock history, soil type, and possible economic returns into consideration. If you have decided to use plant tests, leave the details to the specialist.

It always pays to plan long ahead of planting. Talk to your adviser, discuss your paddock history, results of previous analyses, water availability, your previous problems relevant to that crop with him or her and get your soil analysed if needed a month or two before planting. Use recommended type and rate of fertiliser. This reduces the risk of sacrifying the yield or wasting the fertiliser and normally there would no need for plant test.

In most cases, when a symptom of nutrient deficiency appears on the crop, it would be too late to recover all the losses by top-dressing or foliar feeding. Top-dressing and foliar applications (except for N) are generally less effective than soil applications at or before

Planting. So don't wait for the symptoms. Prevention is cheaper and more assured than the cure.

9.6 Soil test for trace elements essential

The Advocate, August 23, 1994, page 9.

Farm Extra

Soil test for trace elements essential

Forthside DPIF

RESEARCH at the Forthside Vegetable Research Station and on private properties last season has shown that recommendations for trace elements should be based on soil tests.

More than $800,000 is spent annually on trace element fertilisers for vegetables and poppies in Tasmania. Despite this, there are still frequent reports of trace element deficiencies in these crops. There is also speculation that trace elements have been unnecessarily recommended in some instances.

Part of a three-year programme, last season's work was undertaken to see how useful trace elements were when applied using procedures commonly used by vegetable growers.

Trials on poppies and green beans at Forthside and on potatoes, broccoli and sweet corn on private properties were undertaken.

There was no improvement in yield at any of the seven sites, but in some of the potato crops there was significant improvement in the tuber quality. However, at sites where the soil trace element levels were adequate, application of trace elements caused a reduction in yield or in quality of the produce.

The DPIF's crop nutrition specialist, Dr Ali Salardini, said that although these results were only from one year's work, they indicated that growers needed to be careful in their use of trace elements in vegetable production.

"I would recommend growers only put on trace elements where soil tests clearly show the soil is lacking those elements," Dr Salardini said.

Dr Ali Salardini

"Applying extra when there is already enough in the soil is not only a waste of money but may lead to toxic levels resulting, ultimately, in loss of yield or quality."

Dr Salardini stressed that there was still a lot of work to be done before we fully understood the role of trace element fertilisers in vegetable production. The DPIF will be doing at least two more seasons of research work in this area.

If you have a processing crop paddock that returns a soil test low in trace elements, and you are prepared for the DPIF to conduct a trial in that crop, please contact Dr Salardini on 21 7027.

CROP INSPECTION: Dr Salardini inspects a poppy crop which was tested for trace elements prior to planting.

Record entries for Ulverstone poultry show

THERE was a record number of entries in the Ulverstone Poultry Society's annual show held at the showgrounds on Saturday.

The total of 321 birds entered was high for this time of year, according to society president Mr Peter May.

Entries came from as far away as Geeveston, with birds also from Launceston and Longford, as well as locals.

Mr Reg Hope, MLC, opened the show and Mr Vern Host presented trophies to the winners.

West Australian judges Mr Peter Strike and Mr Kevin Nordstrom said birds in some classes were very good.

Mr Nordstrom judged the hard-feathers, soft-feather bantams and water fowl.

Mr Strike judged the soft-feathered large and hard-feathered bantams.

The next show runs in conjunction with the Ulverstone Agricultural Show.

Station hold-up descri

BURNIE CIB has released a description of the clothing worn by a man who held up the Somerset Caltex Service Station, on the Bass Hwy, at gunpoint on Friday night.

Det. Sgt Kerry Daniels said that, according to a witness, the man was wearing a quarter length Drizabone and brown pull-on Blun boots.

He was also wearing a balaclava with formed eye and a roughly cut out mou

The offender is describ

Coastal court