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Fertigation Management of Trellis Tomatoes in Northern Victoria

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Purpose of the report

In recent years, the fresh tomato industry of northern Victoria has moved from a production system using determinate varieties to one using indeterminate varieties. These varieties are higher yielding, require trellising and more intensive management. These distinctions have caused great uncertainty regarding fertiliser management in the industry. Local growers are keen to match their fertiliser applications with crop requirements in order to produce in the most cost-effective manner possible as well as to minimise the environmental impacts of tomato production. As such, guidelines on the efficient fertigation of trellis tomatoes under local conditions are required.

Funding sources and collaborators

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Contents

1. Media Summary

Trellis tomato production is still relatively new to northern Victoria, the primary source of fresh tomatoes the markets of eastern Australia during the Summer and early Autumn. As such, great uncertainty exists in the industry as to optimal fertiliser application. Sap nutrient levels in a number of trellis tomato crops in the Goulburn Valley were monitored during the 2001/2002 season and were related to fertigation practices and crop productivity. The results of the study have been used to create guidelines on efficient fertigation of trellis tomatoes as well as to introduce local growers to the benefits of nutrient monitoring via sap analysis. The growers now have the tools required to match their fertiliser applications with crop requirements in order to produce in the most cost-effective manner possible as well as to minimise the environmental impacts of tomato production. However, results have been obtained for one season only and further validation of the recommendations is required.

It is recommended that trellis tomato growers use sap analysis and compare their results to the benchmarks developed in this project. The amount of a nutrient fertigated should match its removal by the crop less that already in the soil. It is estimated that 228 kg N/ha less any residual available nitrogen should be applied to the crop to make up for the nitrogen removed by a 194 t/ha tomato crop. Application of nitrogen should be timed to meet the demand of the crop to avoid excessive fruit set leading to smaller fruit. Currently, excess nitrogen is applied when the crop is young and cannot be utilised. Nitrogen, potassium and calcium are commonly applied through fertigation. While the benefits of applying nitrogen are evident, the local soils are rich in potassium and large amounts of calcium are applied pre-planting in the form of lime, gypsum and superphosphate. Excess calcium is detrimental to phosphorus uptake and this limits yield. It is recommended that less calcium nitrate is applied through fertigation but a study is needed to compare the effect of using alternative nitrogen forms. These recommendations should be made available to fertiliser and agricultural service providers and used to develop decision-support systems for growers.

2. Technical Summary

In recent years, the fresh tomato industry of northern Victoria has moved from a production system using determinate varieties to one using indeterminate varieties. These varieties are higher yielding, require trellising and more intensive management. These distinctions have caused great uncertainty regarding fertiliser management in the industry. Local growers are keen to match their fertiliser applications with crop requirements in order to produce in the most cost-effective manner possible as well as to minimise the environmental impacts of tomato production.

Sap nutrient levels in a number of trellis tomato crops in the Goulburn Valley were monitored during the 2001/2002 season and were related to fertigation practices and crop productivity. The results of the study have been used to create guidelines on efficient fertigation of trellis tomatoes as well as to introduce local growers to the benefits of nutrient monitoring via sap analysis. The growers now have the tools required to match their fertiliser applications with crop requirements in order to produce in the most cost-effective manner possible as well as to minimise the environmental impacts of tomato production.

It is recommended that trellis tomato growers use sap analysis and compare their results to the benchmarks developed in this project. The benchmarks were developed by using the average sap nutrient levels of the top yielding quartile of crops at various growth stages. Significant relationships were found between high sap nitrate levels during flowering and small fruit size, between high phosphorus sap content and high yield and low calcium content and high yield. These benchmarks should be validated in the coming season before they are widely recommended.

The amount of nutrient fertigated should match the removal by the crop less that already in the soil. The levels of nutrient removed by the crop should be estimated for indeterminate crops under local conditions, but published amounts should be used in the interim. From published results, it is estimated that 228 kg N/ha less residual available nitrogen should be applied to the crop to make up for the nitrogen removed by a 194 t/ha tomato crop. The amount of nitrogen applied per hectare to the monitored crops averaged and ranged between 204 and 604 kgN/ha. The potential contribution of mineralisation of organic nitrogen to the tomato crop needs to be estimated under local soil conditions to provide a better estimate of nitrogen application rates. Pre-planting soil tests should also be performed to estimate the amount of readily available residual nitrogen.

It is important to time the application of nitrogen to match the demands of the crop otherwise excessive fruit set may occur. Current practice applies too much nitrogen when the crop is whereas the bulk of the nitrogen should be applied during fruit filling when demand is greatest.

The common fertigated nutrients in the industry were nitrogen, potassium and calcium applied as calcium nitrate, potassium nitrate and urea. While in general more nitrogen leads to greater yield, the local soils are rich in potassium and large amounts of calcium are applied pre-planting in the form of lime, gypsum and superphosphate. Excessive amounts of calcium have been shown to be detrimental to phosphorus uptake and this, in turn, has limited yield production. It is recommended that less calcium nitrate be applied through fertigation, but a study is needed to compare the effect of using alternative nitrogen forms. An alternative would be to apply more phosphorus, possibly through the drip-tape.

These recommendations should be made available to fertiliser and agricultural service providers and used to develop decision-support systems for growers.

3. Introduction

3.1 Background

Victoria is Australia's major tomato-producing state and is the primary source of tomatoes destined for the fresh market during late Summer and early Autumn. The fresh tomato industry of the region produces approximately 40,000 tonnes annually. The majority of the production is derived from indeterminate varieties grown on trellis. Indeterminate varieties are still relatively new to the industry and are quite sensitive to subtle changes in the nutrition program. Currently great uncertainty exists in the Victorian industry as to the optimum nitrogen and potassium nutrition of indeterminate varieties. Monitoring tools and guidelines for crop nutrition are required by the industry so that inputs can be matched with requirements to increase production efficiency and reduce fertiliser losses to the environment.

3.2 Fertigation

Fertigation is the process of feeding crops by adding soluble fertilisers into an irrigation system. A drip system produces uniform water distribution and can be used to accurately regulate crop feeding. Trellis tomato producers in northern Victoria use drip irrigation exclusively so it makes sense to use the drip system to distribute fertiliser to the crop. Fertigation is particularly beneficial for the management of nutrients such as nitrogen (N) and potassium (K) which are mobile and are required in relatively large quantities later in the season (Hartz and Hochmuth 1996). The precise and uniform application of nutrients to the root-zone through fertigation increases the efficiency of application, saves money and reduces leaching and denitrification. It also saves energy and labour, allows for flexible application, is convenient and importantly, supply can be regulated and monitored (Imas 1999).

This study focuses on nitrogen fertigation since local soils are generally rich in potassium and processing tomatoes do not respond when it is applied (Murray et al. 1996). Although calcium application through fertigation has been recommended for tomato crops in northern Victoria, requirements above the base superphosphate, lime and gypsum additions have yet to be established. Traditional phosphorus fertilisers are relatively insoluble and almost all phosphorus is applied as a base dressing prior to planting.

3.3 Fertigation Scheduling

The availability of nitrogen has the greatest effect of all nutrients on growth rate and uptake rate of other nutrients. Therefore it is the most important nutrient to precisely control (Ingestad 1977). This has been demonstrated in tomatoes where yield and vegetative growth increase with rates of applied nitrogen (Bar-Yosef and Sagiv 1982; Huett 1986).

A simple model for nitrogen budgeting is:

$$N_f=(N_p/E) - N_a$$

where N_f is the amount of N to be applied as fertiliser, N_p is the uptake by the crop, E is the efficiency with which the crop uses the nitrogen (commonly 0.7-0.75) and N_a is the available N measured from soil sample plus potentially mineralisable nitrogen estimated by incubation tests minus losses expected due to denitrification (Feigin et al 1976). Leaching and denitrification can be ignored with well-managed drip systems (Kafkafi et al. 1978, Stark et al. 1983).

It is important not to add excess fertiliser as it not only adds cost to the farmer but leaching of excess nitrogen can contaminate waterways and groundwater adding to further down-stream environmental problems (Pier and Doerge 1995; Thompson and Doerge 1995).

3.3.1 Quantity

The amount of nutrient required, as stated above, depends on the amount available in the soil and may be determined with a preliminary soil test. This quantity will depend on the history of the paddock and could be quite high (for nitrogen) following a previous tomato crop or a legume-based pasture. Nitrogen uptake by the plant is related to fruit yield (Huett and Dettman 1988, Bar-Yosef et al 1980; Halbrook and Wilcox 1980). For example, a 194 t/ha tomato crop has been estimated to remove a total of 572 kg/ha of nitrogen (fruit: 361 t/ha, leaves and stem: 211 kg/ha), whereas a 57 t/ha crop has been estimated to remove 111 kg/ha N (fruit: 79 kg/ha, leaves and stem 32 kg/ha) (Cresswell and Huett 1998). This explains why nitrogen uptake increases with amount of N fertiliser applied (Huett 1986, Stark et al. 1983). Based on previous experience, guides are given for the total amount of nitrogen to be added to a tomato crop without any prior knowledge of soil nitrogen levels or target yields. Some examples of these blanket recommendations are 200 kg/ha in Australia (Rijk Zwaan Australia, unpubl), 180 kg/ha in Florida (Hochmuth 1994) and North Carolina (Sanders 1999) and 50-160 kg/ha in Queensland (Fullelove et al. 1998). Most recommendations fall within the 150-200 kg/ha category. It should be noted that a large amount of residual nitrogen is left in the paddock in the form of leaves and stems that will become available to subsequent crops through mineralisation of the organic matter. Tomatoes are efficient at extracting residual soil nitrogen and the mineralisation component is an important source of nitrogen for tomato crops. Only 40-50% of total plant nitrogen is derived from applied fertilisers (Miller et al 1981), and this figure may fall to as low as 30% where high rates of nitrogen fertiliser are applied (Bar-Yosef and Sagiv 1982).

3.3.2 Timing

Although recommendations vary widely, between 20% (lighter soils) and 40% (heavier soils) of the total nitrogen should be applied prior to planting, usually incorporated with the phosphorus application. These levels are probably most applicable to lighter soils, but studies in heavier sandy loams have demonstrated that optimal yields can be obtained through incorporation of 100% of nitrogen requirements, but only if no significant rainfall occurs during the growing season (Lacascio et al. 1997). The balance of the nitrogen should be applied throughout the remainder of crop growth, usually starting at about first flower. The rate of fertigation depends on the growth stage as tomato plants accumulate nitrogen more rapidly during reproductive growth than vegetative growth (Halbrook and Wilcox 1980). Various recommendations exist as to the best pattern of N fertigation but are based on weekly amounts and give no due accord to the relative growth rate of the crop, which is influenced heavily by temperature (Hochmuth 1994). Other recommendations are based on phenological stages (eg. Fullelove et al 1998).

3.4 Nutrient Monitoring

It is helpful to analyse plant samples weekly in order to adjust the fertigation schedule for a particular crop. These techniques range from gross morphological observations of nutrient deficiencies/toxicities through to analysis of sap and leaf contents. Leaf analysis standards exist for tomatoes (Reuter and Robinson 1997) but are variable, unreliable and must be performed using specialised and time-consuming processes (Huett and Rose 1988). Their use is restricted to benchmarking exercises to tune fertigation programs over many seasons (Fullelove et al 1998). Petiole sap analysis is becoming more popular because of its ease of sample preparation, rapid turnaround and lower cost than leaf analysis. The main disadvantages are that large databases do not exist for diagnostic reference, and there are few published critical concentrations with the exception of nitrate-N. Sap nutrient concentration also depends on the water status of the plant. Critical values for tomato sap nitrogen so far published include figures for semi-indeterminate tomatoes (Huett and Rose 1988), processing tomatoes (Handson and Amenta 1991), fresh determinate tomatoes (Hartz and Hochmuth 1996), and indeterminate tomatoes (Fullelove et al 1998, Hartz and Hochmuth 1996, Serve-Ag Pty Ltd unpubl). Current recommendations dictate that petiole samples should be taken in the cool of the morning while the plants are fully turgid. These samples should then be processed as soon as possible.

4. Materials & Methods

4.1 Experimental Sites

Data were gathered from a total of 24 sites, incorporating the management practices of five growers. Each site was given a reference number from 1 to 24 to ensure confidentiality and these same numbers will be referred to in the results section. Within each site, a 10 m X 4.5 m plot over three rows was used to collect soil samples and petiole samples for sap analysis. Within this plot, a 2 m length of the central row was used to estimate yield and fruit quality. All sites contained cv Red Ruby with the exception of numbers 15 and 24. These sites were excluded from analyses for benchmarking purposes. All sites were conventionally grown using accepted commercial practices with the exception of number 24 that was organically produced under the Biological Farmers of Australia guidelines.

4.2 Fertigation practices

Details on the quantity and frequency of fertigation applied to the experimental sites were collected from the participating growers. It should be noted that not all growers gave details on their fertigation program. We are assuming that the details collected were correct for the purpose of this study, but cannot vouch for their accuracy.

4.3 Soil nutrient status

Soil nutrient status was measured from 8 selected sites at 1st flower stage and when the 3rd truss was ripe. Not all sites could be measured due to the late start of the project in relation to crop growth. Each sample was divided into four distinct depths: 0 – 30 cm, 30 – 60 cm, 60 – 90 cm and 90 – 120 cm. The following tests were performed on the soil samples by the analytical chemistry laboratory at NRE Tatura: pH, EC, Total N (Kjeldahl), NH_4, NO_3, PO_4 (Ohlsen), Total P, K (Skene).

4.4 Petiole sap analysis

Petioles were collected at random from thirty plants within each experimental plot (excluding the sub-plot used for harvest). On collection day, the petioles were harvested from the first fully-expanded leaf prior to 11 am, and refrigerated prior to dispatch by express post to the analytical laboratory at Serve-Ag Pty Ltd in Devonport. The following commercial tests were performed on the extruded sap of these petioles: NO_3, P, K, Ca, Mg and Zn. Samples were taken on a weekly to fortnightly basis depending on the growth rate of the crop. The phenological scale used to group crop stage was that commercially used by Serve-Ag Pty Ltd for indeterminate tomatoes: Stage 1 = 2nd flower, Stage 2 = 3rd flower, Stage 3 = 4th flower, Stage 4 = 5th flower, Stage 5 = 6th flower, Stage 6 = 1st and 2nd truss ripe, Stage 7 = 3rd and 4th truss ripe, and Stage 8 = 5th and 6th truss ripe.

4.5 Yield and fruit quality analysis

Yield was estimated by harvesting ripe fruit on a weekly basis, grading it into small (< 60 mm), medium (60 – 80 mm) and large (> 80 mm) and weighing the different size categories. Six fruit at breaker stage were selected from the third truss of each sub-plot for further fruit quality assessment. These fruit were stored at 20°C for 6 days before assessing their firmness and soluble solids content. Firmness was assessed by measuring compression of fruit after the application of a 500g weight for 5 seconds. Soluble solids content was measured with a portable refractometer using clear serum from the juice extracted from the bulked sampled tomatoes.

4.6 Vegetative growth analysis

Vegetative growth of the tomato plants was estimated by measuring the average distance between trusses on five plants within each experimental plot.

4.7 Statistical analyses and development of benchmarks

Average fertigation amounts and timing were calculated and variability expressed in the form of 95% confidence intervals. The relationships between fertigation levels and yield, % small fruit, soluble solids, firmness and internode length were calculated using linear regression techniques. Similarly, any relationships between sap concentration of the various nutrients at the eight growth stages and either yield, % small fruit, soluble solids, firmness or internode length were determined by linear regression. Average sap nutrient levels at each growth stage for the top yielding quartile of sites were calculated and used to define sap nutrient benchmarks.

5. Results

5.1 Fertigation applied

Only four of the six growers responded to a request for details on their fertigation programs. They used four different types of fertiliser: Urea (46:0:0), $CaNO_3$ (13:0:0), KNO_3 (15:0:38) and "DM3" (13:7:28) (Grow Force Australia Ltd). The total amount of fertiliser applied in elemental form varied extensively between crops (Table 5.1.1). Levels of nitrogen applied ranged from 204 to 604 kg/ha, phosphorus ranged from 0 to 19 kg/ha, potassium ranged from 187 to 741 kg/ha and calcium ranged from 60 to 646 kg/ha.

Table 5.1.1: Average fertigation of nitrogen, phosphorus, potassium and calcium in commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley.

	Quantity of nutrients fertigated (kg/ha)			
	Nitrogen	Phosphorus	Potassium	Calcium
Mean	334	1.9	415	255
Confidence Interval$_{0.05}$	56	2.6	79	101

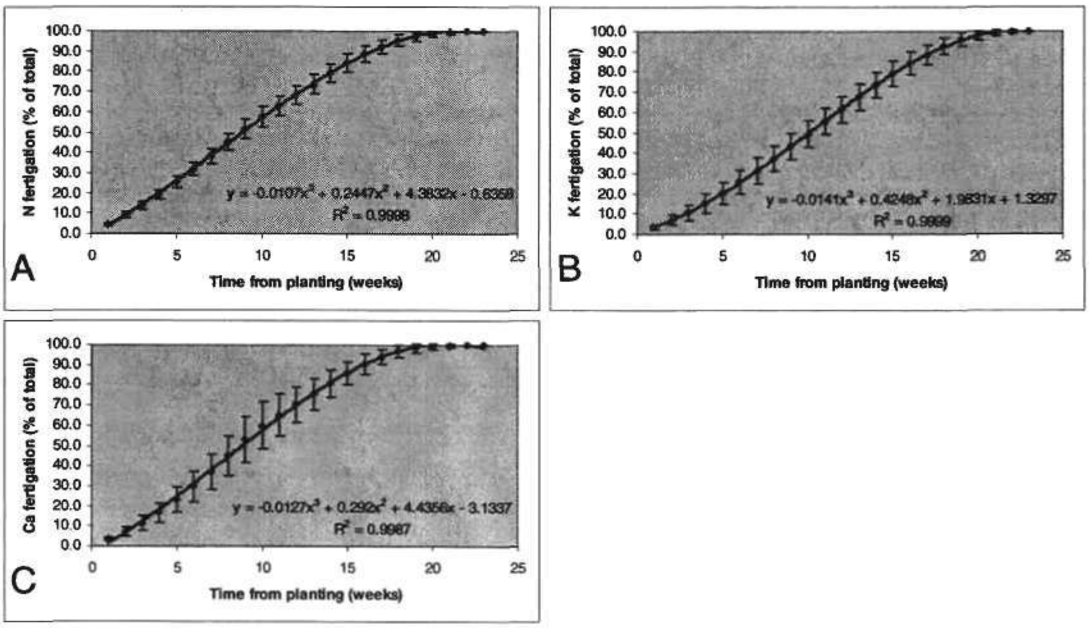

Figure 5.1.1: Proportion of nutrient fertigated over time in commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley. A: nitrogen, B: potassium, C: calcium. Error bars represent 95% confidence intervals.

5.2 Soil nutrient status

Initial soil analyses indicated that average pH of soils in the monitored crops is adequate for tomato production in the top 60 cm of the soil profile. Below 60 cm, pH is too high for optimal tomato production but may be beyond the effective root zone. EC in the top 30 cm of the soil profile is slightly above optimal and could cause productivity loss. Phosphate levels are adequate for tomato production in the top 30 cm but sub-optimal below that. Potassium levels are adequate for tomato production.

While there are no specific recommendations for soil nitrogen requirements, the average levels of ammonium and nitrate equate to 121 kg N/ha in the top 30 cm assuming a topsoil bulk density of 1.25 t/m^3.

Table 5.2.1: Background soil analysis in commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley. Values are expressed in terms of 95% confidence intervals.

	0-30 cm	30-60 cm	60-90 cm	90 – 120 cm
pH	$6.08_{\pm 0.40}$	$6.50_{\pm 0.25}$	$7.38_{\pm 0.50}$	$7.44_{\pm 0.46}$
EC (dS/m)	$0.41_{\pm 0.07}$	$0.28_{\pm 0.03}$	$0.32_{\pm 0.08}$	$0.33_{\pm 0.50}$
Total N (%)	$0.18_{\pm 0.05}$	$0.11_{\pm 0.02}$	$0.07_{\pm 0.01}$	$0.07_{\pm 0.02}$
NH_4^+ (mg/kg)	$10.37_{\pm 3.97}$	$7.34_{\pm 2.52}$	$7.15_{\pm 1.44}$	$4.38_{\pm 1.81}$
NO_3^- (mg/kg)	$83.36_{\pm 16.04}$	$52.19_{\pm 10.05}$	$29.65_{\pm 7.55}$	$31.23_{\pm 10.91}$
PO_4^- (mg/kg)	$22.79_{\pm 5.31}$	$10.33_{\pm 3.03}$	$3.29_{\pm 1.21}$	$4.96_{\pm 2.29}$
Total P (mg/kg)	$49.99_{\pm 22.31}$	$65.36_{\pm 48.96}$	$16.64_{\pm 24.14}$	$8.75_{\pm 3.68}$
K (mg/kg)	$234.15_{\pm 63.14}$	$216.86_{\pm 51.95}$	$208.08_{\pm 33.35}$	$205.08_{\pm 35.5}$

EC appears to have dropped along with phosphate levels and the various forms of nitrogen but potassium appears to be constant. It also appears that pH has increased.

Table 5.2.2: Mid-harvest soil analysis in commercial crops of indeterminate tomato cv Red Ruby during 2001/2002 season in the Goulburn Valley. Values are expressed in terms of 95% confidence intervals.

	0-30 cm	30-60 cm	60-90 cm	90 – 120 cm
pH	$6.45_{\pm 0.48}$	$7.15_{\pm 0.0.69}$	$7.91_{\pm 0.59}$	$7.92_{\pm 0.44}$
EC (dS/m)	$0.30_{\pm 0.17}$	$0.20_{\pm 0.07}$	$0.26_{\pm 0.13}$	$0.27_{\pm 0.16}$
Total N (%)	$0.13_{\pm 0.03}$	$0.08_{\pm 0.02}$	$0.04_{\pm 0.01}$	$0.04_{\pm 0.01}$
NH_4^+ (mg/kg)	$7.05_{\pm 3.95}$	$3.34_{\pm 1.00}$	$2.55_{\pm 0.65}$	$2.18_{\pm 0.37}$
NO_3^- (mg/kg)	$43.31_{\pm 31.18}$	$22.55_{\pm 13.82}$	$14.20_{\pm 10.49}$	$13.20_{\pm 7.98}$
PO_4^- (mg/kg)	$15.09_{\pm 7.09}$	$4.74_{\pm 5.15}$	$1.66_{\pm 1.08}$	$2.18_{\pm 1.25}$
Total P (mg/kg)	$27.04_{\pm 11.99}$	$8.63_{\pm 8.18}$	$3.36_{\pm 1.78}$	$3.64_{\pm 2.05}$
K (mg/kg)	$258.66_{\pm 122.48}$	$238.39_{\pm 132.57}$	$191.19_{\pm 70.19}$	$173.24_{\pm 52.78}$

5.3 Petiole sap analyses

Sap nutrient levels were measured for all sites at various key growth stages. All sap nutrient levels varied between crops at the given growth stages. On average, nitrate levels dropped with age of the plant, from an average of 6000 ppm at second flower stage down to 2500 ppm during the final harvest (Fig. 5.3.1A). Sap phosphorus levels fell during growth from an average of 175 ppm at second flower stage down to 80 ppm during the final harvest (Fig. 5.3.1B). Sap potassium levels tended to rise during crop growth, from an average of 4400 ppm to 5500 ppm at final harvest (Fig. 5.3.1C). Sap calcium levels remained relatively static, starting at 750 ppm and finishing at 800 ppm (Fig. 5.3.1D). Sap magnesium levels generally increased with growth from an average of 420 ppm to 620 ppm at final harvest (Fig 5.3.1E). Sap zinc levels generally increased with growth from an average of 2.5 ppm through to 5 ppm at final harvest (Fig 5.3.1F).

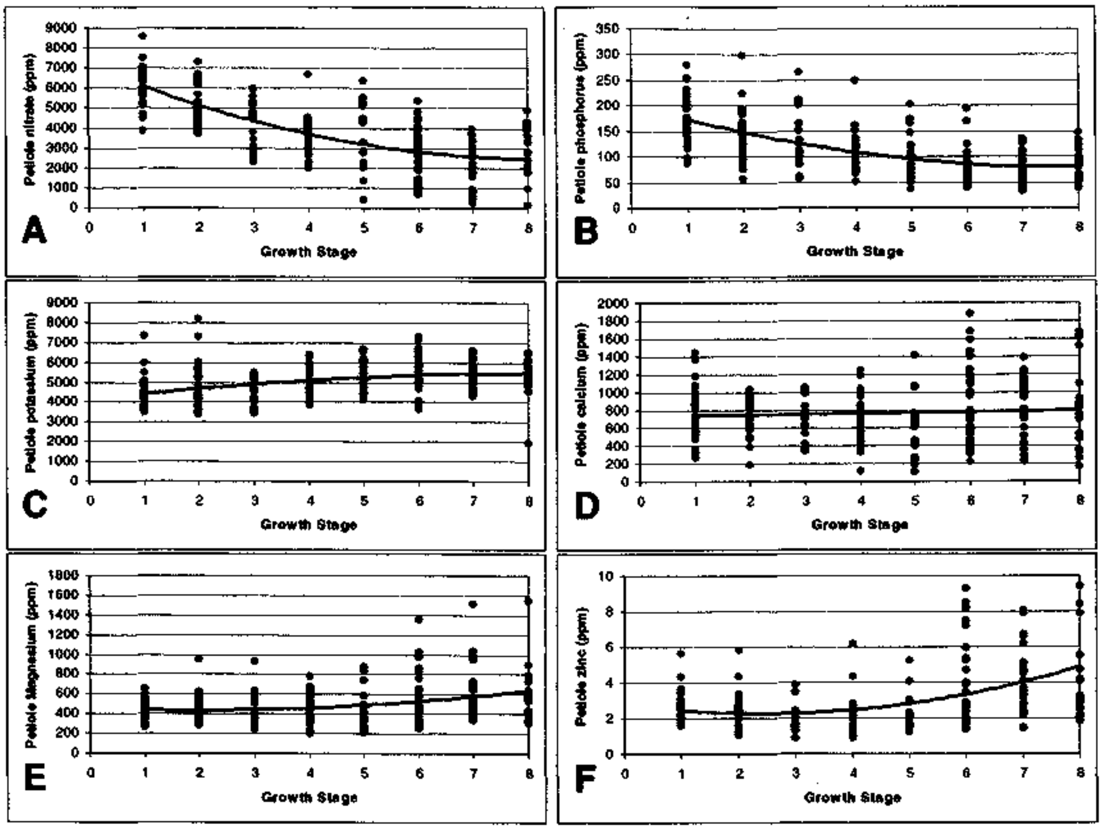

Figure 5.3.1 Sap nutrient levels at various growth stages in commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley. A: nitrate, B: phosphorus, C: potassium, D: calcium, E: magnesium, F: zinc.

5.4 Yield and quality analysis

Total yields for the different sites ranged from 117 to 228 t/ha for conventionally produced crops (average 166±13), and 80 t/ha for the organic crop (Fig 5.4.1A). The proportion of the tomatoes that were in the small category ranged from 30.4 through to 60.2% (Fig. 5.4.1B). The proportion of the yield that were in the medium category ranged from 35.1 to 61.7% (Fig. 5.4.1C). The yield proportion comprised by large fruit ranged from 1.9 to 14.9% (Fig. 5.4.1D). Soluble solids contents from the sites ranged from 3.6 to 4.9% (Fig. 5.4.1E). Firmness of the tomatoes from the monitored sites ranged from 0.63 cm through to 1.42 cm of distortion (Fig. 5.4.1F).

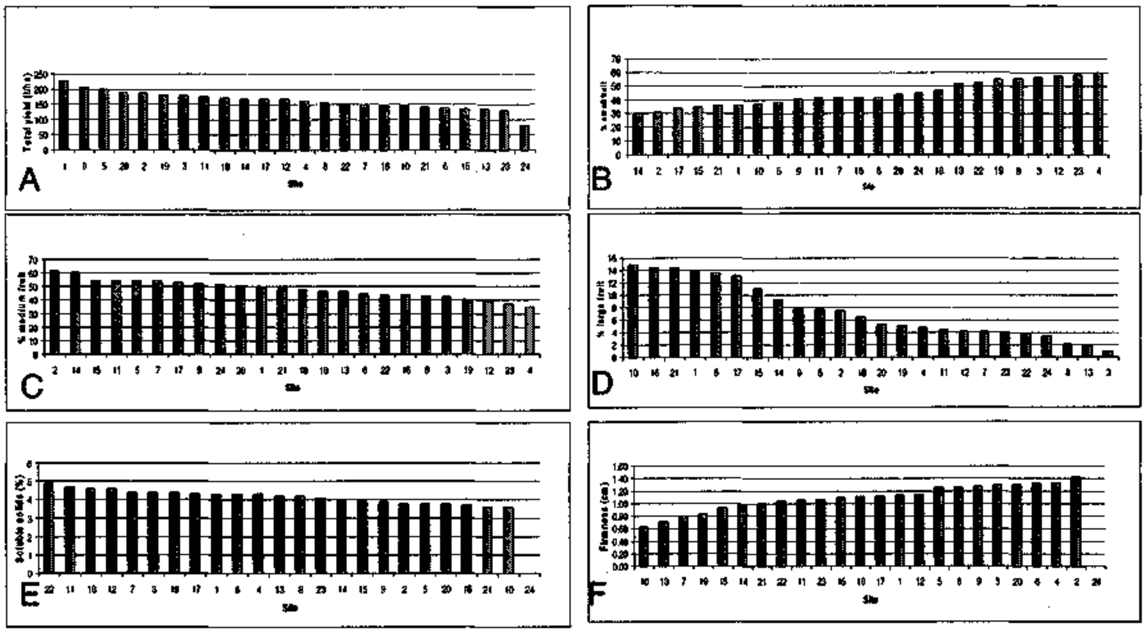

Figure 5.4.1 Yield and fruit quality attributes in commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley. A: Total yield, B: % Small fruit, C: % Medium fruit, D: % Large fruit, E: Soluble Solids, F: Firmness.

5.5 Vegetative growth analysis

The average inter-truss spacing ranged from a minimum of 10.8 cm to a maximum of 52.7 cm with a mean of 24.4 cm. Although the range was quite large the 95% confidence interval was 2.8 cm, indicating that results were quite uniform on the whole.

5.6 Effect of fertigation levels on yield

Relationships between fertigation levels and yield are presented in Fig. 5.6.1. A significant ($P=0.003$) positive relationship existed between total yield and amount of nitrogen fertigated (Fig. 5.6.1A). A similar positive relationship also existed between total yield and amount of potassium fertigated ($P<0.001$) (Fig. 5.6.1B) and amount of calcium fertigated ($P=0.013$). It should also be noted that, since potassium and calcium were solely applied in nitrogenous forms, these results are confounded and should be interpreted accordingly.

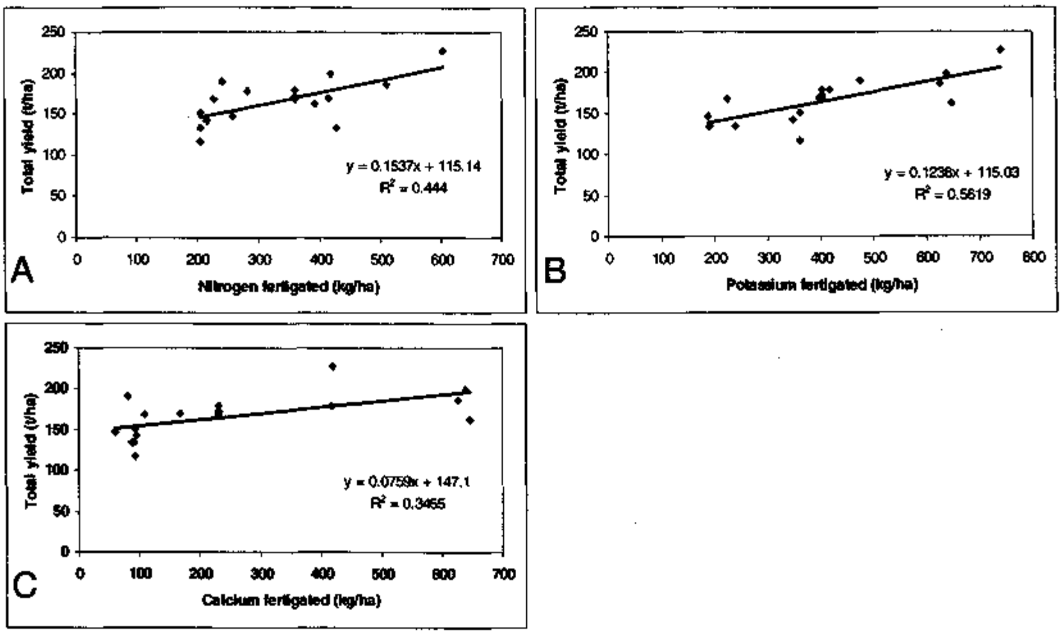

Figure 5.6.1: Relationship between fertigation amounts and total yield in commercial crops of indeterminate tomato cv. Red Ruby during the 2001/2002 season in the Goulburn Valley. A: Nitrogen fertigated, B: Potassium fertigated, C: Calcium fertigated.

5.7 Effect of sap nutrient levels on yield, fruit quality and vegetative growth

The significance of the relationships between sap nutrient levels at the various growth stages and fruit yield were examined through linear regression analysis and the results are presented in Table 5.7.1. Significant relationships were found between levels of most sap nutrients and total yield for at least one growth stage. Consistent results were limited to few nutrients. There were significant positive relationships between phosphorus levels and total yield at most growth stages. On the other hand, significant negative relationships were apparent between calcium levels and total yield in half the growth stages. In fact, a significant negative relationship was evident between sap phosphorus and sap calcium throughout growth. Magnesium levels may have some impact on total yield but no clear pattern was obvious. Similarly, sap potassium levels after the commencement of harvest have a significant positive effect on yield at the 10% level.

Table 5.7.1: Significance and nature of the relationships between sap nutrient levels at various growth stages and total fruit yield from commercial sites of indeterminate tomato cv. Red Ruby during the 2001/2002 season in the Goulburn Valley.

Growth Stage	**Significance of relationship between sap nutrient and total yield (*P*)***					
	Nitrate	**Phosphorus**	**Potassium**	**Calcium**	**Magnesium**	**Zinc**
1	0.27	0.35	0.35	**0.02^{-}**	0.13	0.72
2	**0.001^{+}**	**0.03^{+}**	0.44	**0.04^{-}**	0.75	0.22
3	0.79	**0.03^{+}**	0.56	0.86	**0.03^{-}**	0.12
4	0.06	**0.001^{+}**	0.26	**0.01^{-}**	0.3	0.09
5	0.95	0.17	0.82	0.11	0.4	0.26
6	0.79	**0.006^{+}**	**0.01^{+}**	**0.02^{-}**	**0.04^{-}**	0.42
7	0.64	0.28	0.07	0.22	**0.04^{-}**	0.76
8	0.15	**0.04^{+}**	0.08	0.2	0.18	0.41

*Figures in bold refer to significant relationships at the 5% level, the sign of the relationship is indicated as a superscript

Sap nutrient levels were also found to significantly affect fruit size but not other measured quality parameters such as soluble solids content or firmness. The significance of the relationships between sap nutrient levels at the various growth stages and % small fruit were examined through linear regression analysis and the results are presented in Table 5.7.2. The only consistent result to emerge is that a significant positive relationship exists between sap nitrate levels during flowering and the proportion of small fruit produced.

Table 5.7.2: Significance and nature of the relationships between sap nutrient levels at various growth stages and % small fruit from commercial sites of indeterminate tomato cv. Red Ruby during the 2001/2002 season in the Goulburn Valley.

Growth Stage	**Significance of relationship between sap nutrient and % small fruit (*P*)***					
	Nitrate	**Phosphorus**	**Potassium**	**Calcium**	**Magnesium**	**Zinc**
1	**0.03**$^{+}$	0.27	0.94	**0.02**$^{+}$	0.39	**0.03**$^{-}$
2	**0.001**$^{+}$	0.75	0.58	0.27	0.57	**0.03**$^{-}$
3	0.06	0.74	0.30	0.98	0.25	0.23
4	**0.001**$^{+}$	0.32	0.61	0.16	0.20	0.81
5	0.21	0.21	0.42	0.45	0.93	**0.03**$^{-}$
6	0.39	0.74	0.10	**0.04**$^{+}$	**0.01**$^{+}$	0.37
7	0.37	0.34	**0.01**$^{-}$	0.22	0.07	0.15
8	0.42	0.75	0.415	0.17	0.55	0.17

*Figures in bold refer to significant relationships at the 5% level, the sign of the relationship is indicated as a superscript

Sap phosphorus concentration had a significant effect on stem length between trusses but was largely influenced by one outlier and therefore has been discounted. No other significant effects were found.

5.8 Critical sap nutrient levels based on the top yielding quartile

The top yielding quartile was used to calculate critical sap nutrient levels. According to the data collected over the 2001/2002 season, any deviation from the critical levels will result in a decline in yield in the respective crop. The critical levels can also be compared with the average levels of all of th crops monitored as indicated on Fig. 5.8.1. Where the average level is higher than the critical level indicates over fertilising and where the average level is lower indicates general under fertilising in the monitored crops. The critical level for nitrate is lower than the average for all crops during the flowering stages (stages 1 – 4), but the same during the harvest stages. A similar relationship exists for potassium, although the critical level is higher than the crop average during harvest. The critical level of sap phosphorus and sap zinc is higher than average crop levels over the past season. The opposite is evident with sap calcium and sap magnesium with critical levels lower over the all growth stages when compared with the performance of all crops over the past season.

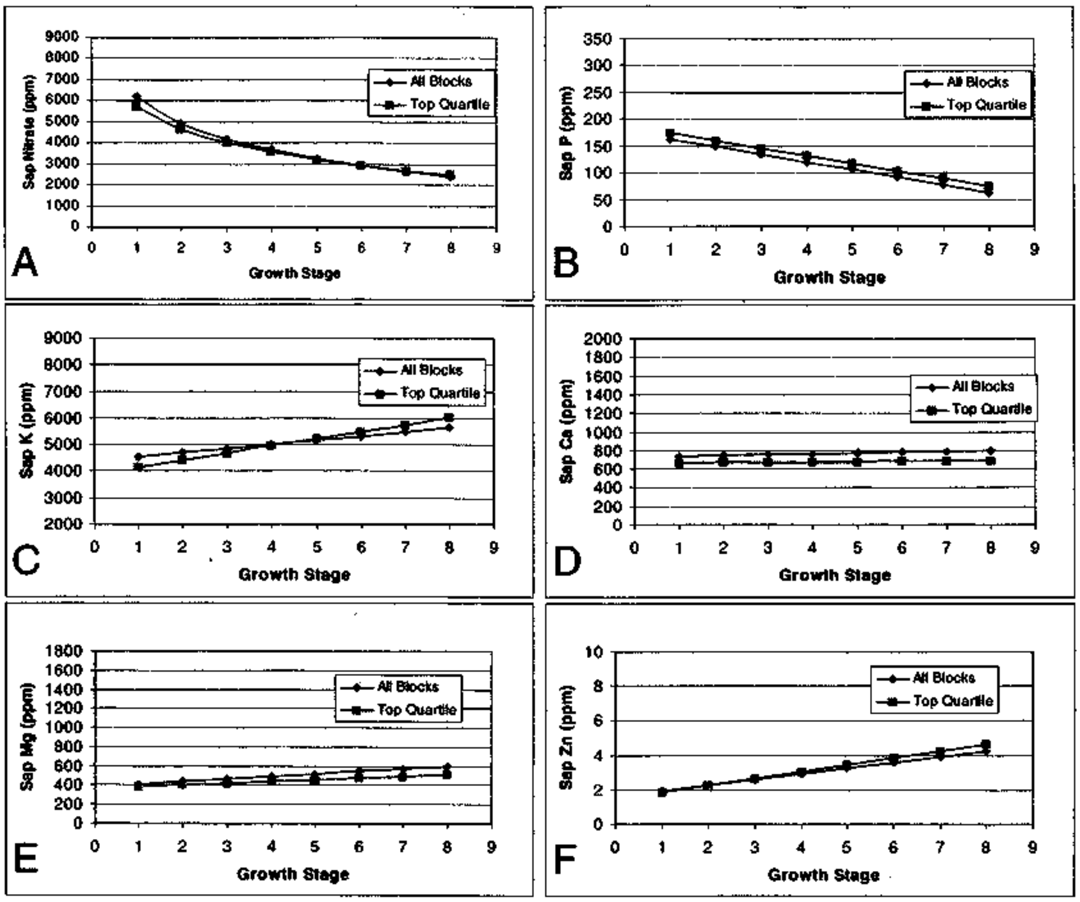

Figure 5.8.1 Critical levels of sap nutrients based on top yielding quartile of commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley. A: Nitrate, B: Phosphorus, C: Potassium, D: Calcium, E: Magnesium, F: Zinc.

6. Discussion

6.1 Crop performance

6.1.1 Yield

Yield varied widely between crops, with some showing the potential to produce more than 200 t/ha. While not all yield variation can be attributed to nutrition, significant relationships were seen between nitrogen fertigation and yield which accounted for 44% of the total variation. Similar trends of increasing yields of tomatoes with applied nitrogen have been previously reported (Bar-Yosef and Sagiv 1982, Huett 1986). Similar trends were seen with fertigated calcium and potassium but the results were confounded with nitrogen. Some of the variation in yield has also been attributed to sap phosphorus and sap calcium levels, and to a lesser extent, sap potassium levels in the post-flowering stage. Yield increased as sap phosphorus levels increased and sap calcium levels decreased. Other possible factors affecting yield include soil type, irrigation management, pruning, climatic conditions and pest control.

6.1.2 Fruit quality

The concentration of sap nitrate during the flowering phase of growth significantly affected the size distribution of the crop. Elevated nitrate levels in the tomato plant during the flowering phase increased the proportion of small fruit, presumably due to increased flowering and fruit set. One of the responses that tomato plants have to nitrogen is through flowering and presumably the elevated sap nitrate levels increased flowering and fruit set resulting in the production of more fruit of a smaller average size. The extent of this effect may change depending on the variety's floral responsiveness to nitrogen. In general, growers require medium to medium/large tomatoes.

Tomato fruit firmness and soluble solids can be affected by nutrition, especially through the application of nitrogen and potassium (Huett 1986, Huett and Dettman 1988). However, there was no evidence of such an effect in the present study. In general, all fruit measured were firm enough for marketing (<15 mm compression). However, almost all fruit had soluble solids contents below what is desirable (> 4.5%). In general, the higher the soluble solids, the higher the perception of flavour (Stevens et al 1977).

6.1.3 Vegetative growth

Sap nutrient content was not significantly related to vegetative growth as measured by stem elongation.

6.2 Fertigation practices

6.2.1 Quantity

Although yield increases with applied nitrogen, the efficiency of nitrogen use drops to a level which makes it uneconomic to apply. Furthermore, excess nitrogen can reduce phosphorus uptake (Gunes et al 1998, He et al 1999). In our study, P appeared to be a sap nutrient that was limiting yield. Some crops had in excess of 500 kg N/ha applied post-planting, of which less than 40% would have been taken up by the plant. This is not only a waste of money but may pollute groundwater or waterways and reduce fruit quality. Figure 5.6.1A showed comparable yields between two crops, one with 250 kg N/ha and the other with greater than 500 kg N/ha. If a 194 t/ha crop removes 572 kg N/ha (Cresswell and Huett 1998), of which only 40% is derived from fertiliser sources (Miller et al. 1981), then only 228 kg N/ha needs to be applied after correction for readily available soil nitrogen. This figure accords well with the general recommendations given for tomatoes of between 150 and 200 kg N/ha. The remaining 60% of the nitrogen removed by the tomato crop is derived from residual soil nitrogen, especially through the mineralisation of organic nitrogen. In the present study, the average 0.18% total nitrogen present in the top 30 cm of the soil profile equates to approximately 6750 kg N/ha, assuming a soil bulk density of 1.25 t/m^3. Approximately 5% of the total N (338 kg N/ha) would need to be mineralised to achieve the given removal rate. In turn, 211 kg N/ha will be returned to the soil tomato crop residues are incorporated rather than being removed or burnt (Cresswell and Huett 1998). In order to more precisely forecast the N fertiliser requirements for trellis tomatoes in northern Victoria, we must be able to estimate nitrogen removal rates and the soil nitrogen mineralisation activity.

The potassium levels of the soil were non-limiting to yield according to the figures of Murray et al. (1996). As such, potassium may not be required as a fertigation nutrient. Potassium depletion could be corrected simply by the addition of potash prior to the planting of subsequent crops.

The addition of calcium by the fertigation system is relatively new to the industry but is now widely practiced by trellis tomato growers. Calcium is routinely applied pre-planting in the form of lime to correct pH imbalances, with superphosphate and with gypsum to address soil structural issues. The routine recommendation for gypsum is 2.5 t/ha that would easily cover the 83 kg/ha removed by the crop (based on the figures of Huett and Dettman 1988).

6.2.2 Timing

No data were taken on the amount of nitrogen that was applied prior to crop establishment, but the soil analyses that were taken after planting includes those amounts. By applying nitrogen as the plant uses it, the risk of losses due to leaching is decreased. This is not as important when using drip irrigation on heavy soils (Lacascio et al. 1997) and some to all of the nitrogen could be applied pre-plant. However, our results have shown that excess nitrogen during flowering leads to more small fruit and this may be corrected by reducing the amount of nitrogen applied pre-planting and applying the nitrogen only when the plant requires it.

Based on published uptake rates (Cresswell and Huett 1998), Figure 6.2.2 represents the theoretical proportion of total fertigation N that should be applied over time and compares it with actual data collected during the current study. In practice, trellis tomato growers in the Goulburn Valley are applying excess nitrogen but are applying it at a stage where the plants are not able to utilise it, increasing the risk of leaching and probably leading to excessive flowering and small fruit size. There was little variation in the timing of N application when compared with potassium and calcium indicating the uncertainty with which the latter nutrients are applied.

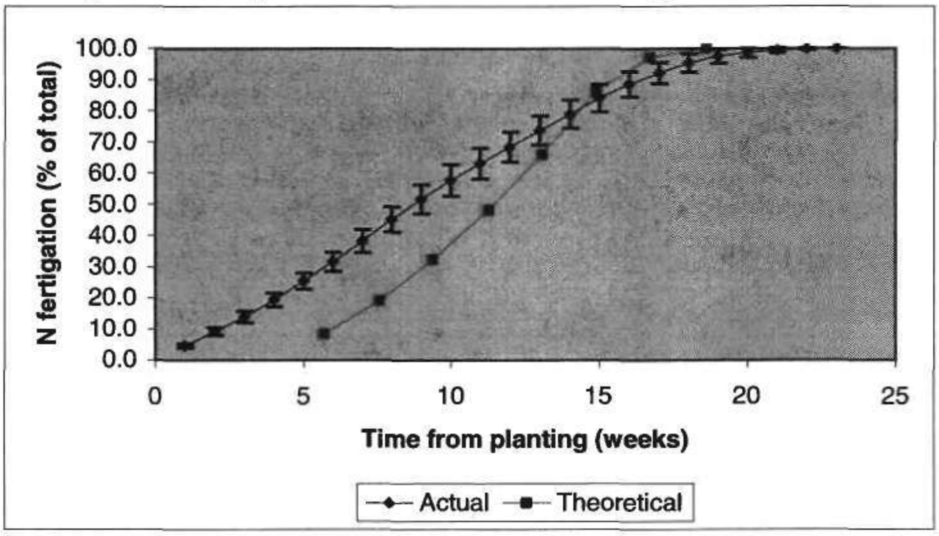

Figure 6.2.2: Theoretical proportion of total fertigation N that should be applied to a tomato crop weekly, as compared with actual data derived from commercial crops of indeterminate tomato cv Red Ruby during the 2001/2002 season in the Goulburn Valley

6.2.3 Nutrient Forms

Urea comprised 19% of the total nitrogen applied on average to the monitored crops. Nitrogen was applied mainly as calcium nitrate (32%) and potassium nitrate (49%), both of which are more expensive forms of nitrogen. Large amounts of calcium are typically applied prior to planting in the form of lime and gypsum. With the fertigated calcium as well, a large reserviour of Ca builds up in the soil, the effects of which are not clear. Sap calcium was negatively correlated with sap phosphorus, and sap phosphorus was limiting yield. Excess calcium has been shown to be antagonistic to phosphorus uptake in a soilless culture (Gunes et al 1999). In a soil-based system, phosphorus is immobilised as insoluble calcium compounds in higher pH soils whereas insoluble aluminium and iron compounds may be formed in high clay soils (Glendinning 2000). An alternative would be to use more phosphorus or fertigate with phosphorus (Papadopolous and Ristimaki 2000). If potassium is not required as part of the fertigation program as suggested earlier, urea and ammonium nitrate can be used exclusively as sources of nitrogen for fertigation in our high potassium and calcium tomato cropping soils.

Ammonium fertilisers should be used in moderation as ammonium toxicity occurs in tomatoes (Jones 1999).

6.3 Nutrient monitoring

The benchmarks defined in this study were based on the top yielding quartile of all crops. In any such analysis, the benchmarks are limited to the range of data surveyed. In the present study, no low sap nitrogen crops existed and therefore the benchmarks require further validation in coming seasons and with different varieties. The benchmark defined in this study have been compared to published sap nitrate guidelines (Fig 6.3.1) and is similar to that defined for greenhouse tomatoes in Florida (Hartz and Hochmuth 1996), but starts higher and finishes lower, something that may be due to the pattern of fertigation application by local growers. The benchmarks defined by Reuter and Robinson (1997) are higher and the other benchmarks are lower, possibly because they are for determinate or semi-determinate plant types. The phosphorus and calcium results suggest that those elements were limiting yield; insufficient phosphorus and excess calcium.

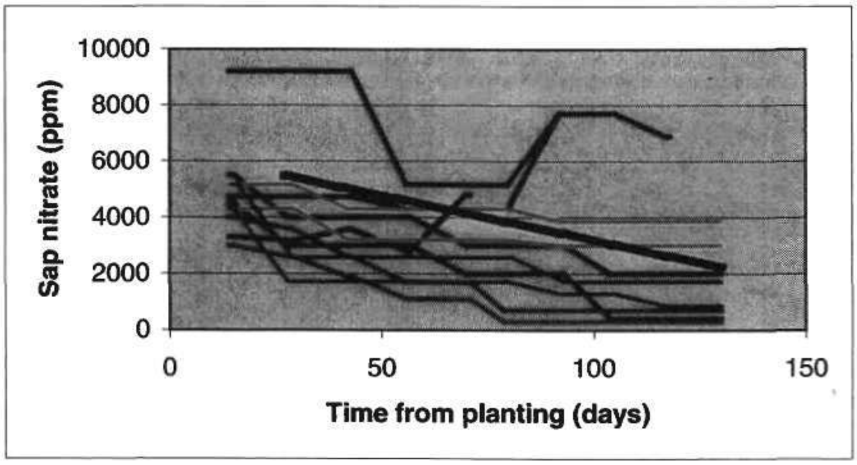

Fig 6.3.1: Sap nitrate benchmark (black) as compared with published guidelines: Reuter and Robinson (1997) (blue), Florida greenhouse (Hartz and Hochmuth 1996) (light blue), Florida field (Hartz and Hochmuth 1996) (red), NSW semi indeterminate (Huett and Rose 1988) (purple), Queensland (Fullelove et al 1998) (green), Australian processing tomato (Handson and Amenta 1991) (pink).

Sap testing as a monitoring tool has been criticised because of its sensitivity to plant moisture status and therefore time of sampling, and requirements for rapid testing. However, the results of our study were consistent and we are confident that the technique can help with the fertigation management of trellis tomatoes. Interpretation of results will be greatly aided by the collection of further crop data.

7. Technology Transfer

7.1 Individual feedback

Participating growers were provided with feedback on the sap nutrient contents of their tomato crops on a fortnightly basis. During the week of 24th June 2002, these same growers were also given feedback on their crops' performances over the season as compared with the rest of the industry.

7.2 Group feedback

The results of the project were presented to the industry at the Annual General Meeting of the Northern Victorian Fresh Tomato Growers' Association on 21st June 2002.

7.3 Written

Results of the project were published in the Tomato Feature edition of Good Fruit and Vegetables:

Ashburner R, Top M and Schulz M. 2002. Balancing nutrient use with fertiliser application in trellis tomato crops. *Good Fruit and Vegetables*, Sept. p35.

8. Recommendations

Monitoring: It is recommended that trellis tomato growers use sap analysis and compare their results to the benchmarks developed in this project. These benchmarks should be validated with further data collection in the coming season before they are widely recommended.

Amount of nutrient fertigated: The amount of nutrient fertigated should match the removal by the crop less that already in the soil. The levels of nutrient removed by the crop should be estimated for indeterminate crops under local conditions, but published amounts should be used in the interim. It is estimated that 228 kg N/ha less residual available nitrogen should be applied to the crop to make up for the nitrogen removed by a 197 t/ha tomato crop. The potential contribution of mineralisation of organic nitrogen to the tomato crop needs to be estimated under local soil conditions to provide a better estimate of nitrogen application rates. Pre-planting soil tests should be done to estimate the amount of residual nitrogen that is readily available to the plant.

Timing of fertigation: It is important to time the application of nitrogen to the demand of the crop otherwise excessive fruit set may occur. Current practice applies too much nitrogen when the crop is young and the guidelines set out in the discussion should be followed.

Form of nutrient: The common fertigated nutrients in the industry were nitrogen, potassium and calcium. While the benefits of applying nitrogen are self evident, the local soils are rich in potassium and large amounts of calcium are applied pre-planting in the form of lime, gypsum and superphosphate. Excessive amounts of calcium have been shown to be detrimental to phosphorus uptake and this, in turn, has limited yield production. It is recommended that less calcium be applied through fertigation but a study needs to be made to compare the effect of using alternative nitrogen forms. An alternative would be to apply more phosphorus, possibly through the drip-tape.

Uptake of technology: These recommendations should be made available to fertiliser merchants and agricultural service providers to aid in the uptake of the technology.

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