Integrated crop management of fresh market tomatoes in northern Victoria

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VIC Department of Primary Industries

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FINAL REPORT

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Purpose of the Report
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Media Summary

Fresh market tomato growers in northern Victoria have new tools to reduce insect damage in their crops and improve the nutrition on their crops, as a result of a project recently completed by scientists at DPI Tatura. The project, funded by Horticulture Australia Limited, DPI Victoria and the Northern Victorian Fresh Tomato Industry Development Committee, identified that the current calendar spray based programs missed peak egg lays for the major insect pest, *Helicoverpa* moths.

The project team developed a sampling protocol to allow growers to accurately and quickly monitor moth egg populations. They also monitored pesticide resistance levels and determined the source of moths. Up to 30% of the moths had migrated from NSW or QLD.

A resistance management strategy was developed, taking consideration of the need to control other pests in the crop, insecticide use by other crops in the Goulburn Valley region and the likely use of pesticides in alternate crops in NSW or Qld.

In recent years, the fresh tomato industry in northern Victoria has moved to a new production system using indeterminate varieties. These varieties require trellising and more intensive management, and are sensitive to nutrient application. The lack of local information on agronomic practices such as crop nutrition has led to variation in approaches to maximise crop yield and fruit quality. The result has been some inefficient practices that may impact on crop performance and potentially also on the environment.

Sap nutrient levels were monitored in a number of trellis and ground tomato crops in the Goulburn Valley Region over the last three seasons, and were related to measures of crop productivity. Analysis of the fertiliser program used by growers indicated that improvements could be made in both the timing and quantity of applications to better meet plant requirements. Results of the study have been used to develop benchmarks for efficient fertiliser application to fresh tomatoes, as well as introducing local growers to the benefits of nutrient monitoring by sap analysis. Developed under local conditions and management practices, these benchmarks will allow Victorian growers to maximise their productivity by matching their fertiliser applications with crop requirements, as well as to minimise leakage of nutrients to the surrounding environment.

The improved fertiliser program, the egg-monitoring program, and the resistance strategy have been distributed to growers in time for the 2005/2006 season.

Technical Summary

Integrated crop management (ICM) recognises that every farm works as an integrated system and that each aspect of farm management can have an impact on other areas of production. The Fresh market tomato industry in Northern Victoria currently relies on insecticide applications every 7-10 days to control the primary pest, Helicoverpa. This practice is inefficient, and can lead to development of resistance to pesticides by the target pest. The industry has also recently moved significantly to production of indeterminate tomato varieties grown on intensive trellis systems. These varieties are sensitive to nutrient application but lack of information is contributing to inefficient nutrient management practices which impact on the environment, crop yield, and fruit quality.

The project team set out to investigate two elements of ICM, integrated pest management (IPM) and fertiliser management, in fresh market tomato crops in Northern Victoria. The research was divided into discrete studies that complemented each other. For example, it was important to know which Helicoverpa species caused damage at various stages of the crop, how migration of the various Helicoverpa species affected pest population dynamics and efficacy of pesticide applications, how management of Helicoverpa impacted on management of other pests and development of resistance and if nutrient status of the crop affected its attractiveness to pests.

The industry demanded that the research was conducted on commercial farms but individual growers were reluctant to risk sufficient crop area for replicated plot trials on Helicoverpa management. A compromise was negotiated in which spray programs were analysed and related to egg numbers in the crop. A comprehensive sampling plan that allows the pest scout to vary sample size based on individual farmer action thresholds for Helicoverpa egg counts was developed. Data from pheromone traps, spray records, egg counts, and damage assessments were analysed. Timing of peak egg numbers, duration and magnitude of the peaks, and species involved varied from year to year and reinforced the inefficiency of calendar spraying. Very few growers timed sprays to coincide with critical oviposition periods despite having been supplied with the data, and many applied the same chemical groups multiple times and over consecutive generations of Helicoverpa, thus increasing potential for resistance.

DNA analysis using microsatellite marker technologies in collaboration with the University of Queensland demonstrated that about 30% of moths caught in the region were immigrants from NSW and Qld. Both long and short distance migration makes resistance management difficult unless resistance management strategies are implemented on a regional scale. A resistance management strategy suitable for individual farms or whole regions was developed. The strategy considered the use of particular chemicals against other pests such as Western flower thrips, mites, aphids and leafhoppers. The strategy was presented as a simple chart that indicated the most appropriate timing for application of each group of chemicals to minimise the rate of development of resistance by the pests.

Helicoverpa armigera has a different resistance spectrum to *Helicoverpa punctigera* and their relative importance varies with seasonal conditions. *H. punctigera* accounted for 68% of the damage sustained in 2003/04 but in 2004/05 *H. armigera* caused 88% of the damage.

Preliminary benchmarks for pesticide sap analysis had been developed previously and the industry requested that these be validated in commercial crops. Petiole sap from 92 trellis and ground tomato crops was analysed at selected growth stages and related to fruit yield and quality. Petiole nitrogen levels were negatively related to yield and fruit size, particularly at early growth stages, and benchmark values suggested that some growers are applying excessive nitrogen. The relationship between Phosphorus, micronutrients, and fruit yield and quality was inconsistent and requires further work.

Adoption of egg monitoring, a regional resistance management strategy, and petiole sap analysis for nutrient management would reduce the environment impact of tomato production and improve yields.

Introduction

The fresh market tomato industry in Northern Victoria has a farm gate value of approximately $50 million and is comprised of 20 growers, who produce 45,000 tonnes of fresh tomatoes on 400ha. Consumers demand high quality fruit and vegetables at minimum cost and produced with minimal impact on the environment. As such, there is increasing pressure on fresh market producers to match production inputs with crop requirements in order to maintain quality, reduce wastage and to demonstrate to consumers that they produce in an environmentally responsible manner. Since production of tomatoes on a trellis system is still relatively new in northern Victoria, the use of agronomic inputs such as insecticides or fertilisers vary widely. There is a need to develop an integrated crop management (ICM) approach, which will provide guidelines for crop production / input requirements that minimise environmental impacts across the industry.

ICM recognises that every farm works as an integrated system and that each aspect of farm management can have an impact on other areas of production. This project examined two elements of ICM, (a) integrated pest management (IPM) and (b) fertiliser management, in fresh market tomatoes in northern Victoria.
The fresh market tomato industry relies on insecticide application every 7 to 10 days to control the primary pest *Helicoverpa*. This practice results in unnecessary spray applications and misses key insecticide application windows leading to an increase in production costs and high fruit damage. IPM uses a range of techniques to effectively control pests. In this project, a range of pest management techniques were targeted to improve control, including resistance testing, *Helicoverpa* migration studies, resistance management strategies and pest monitoring to improve timing and efficacy of chemical controls.

In recent years, the fresh market industry has moved significantly to production of indeterminate tomato varieties, which require trellising and more intensive management. Such varieties are sensitive to nutrient application. Farmers are currently trying many strategies in order to maximise their yields. The lack of information on the subject is leading to inefficient practices, which may impact on crop yield and quality and potentially the surrounding environment. This project provided growers with guidelines and monitoring tools to maximise the effectiveness of their fertiliser applications. Similar guidelines and monitoring tools will be developed for growers of determinate varieties.

The impact of this work will increase productivity and sustainability of tomato crops in the region using a more advanced pest control strategy and improved nutrient management.

Integrated Pest Management (IPM) - Managing the primary pest species *Helicoverpa*

Contents

General Introduction

Heliothines are pests of world-wide economic importance, attacking a wide range of vegetable and grain crops (Zalucki et al 1986). Two Heliothine pests, *Helicoverpa armigera* and *Helicoverpa punctigera* cause considerable damage to fresh market tomato crops in the Goulburn Valley. *Helicoverpa punctigera* is the native budworm, which migrates into cropping regions from inland Australia in spring each year. *Helicoverpa armigera* is the tomato budworm and it overwinters in cropping regions.

The crops that these species feed on include nearly all major field crops (eg. Cotton, maize, chickpeas, lupins and wheat) and horticulture crops (eg. Sweetcorn, lettuce, apples and tomatoes). These species can also colonise wild plants in both cropping and non-cropping areas (Fitt 1989, Zalucki et al 1994). This means that females can exploit a succession of cultivated and uncultivated hosts through the season (Fitt 1989). It is the habit of feeding on flowering and fruiting parts, and the highly polyphagous nature of both Heliothines that contribute to their status as major insect pests in agriculture in Australia and overseas (White et al 1996, Fitt 1989). As well as this both species have high mobility, with both long distance and short distance (local) migration occurring. Both species also have a high fecundity, with moths laying 1000 plus eggs in their lifetime. These factors mean that *Helicoverpa* can easily find host plants and multiply rapidly.

In the Victorian fresh market tomato industry, pest management decisions are currently based on routine calendar spray programs with 7-10 day intervals. These spray programs are neither efficient nor environmentally sustainable methods of pest control. Fresh market tomatoes are a high value crop with low damage thresholds and fruit damaged by *Helicoverpa* is unmarketable. Damage levels from *Helicoverpa* can be as high as 17%.

This report examines a number of aspects of *Helicoverpa* biology and management. The implications of resistance, migration and timing of chemical applications on the control of *Helicoverpa* are investigated. Current practices will contribute significantly to an increase in resistance to many of the chemicals currently available, eventually leading to field failure of these chemicals. Resistance levels for *H. armigera* and *H. punctigera* were examined. Initial results of resistance testing in the district (IPM project VG98150) found that high levels of resistance to pyrethroids and carbamates was present in the *Helicoverpa armigera* populations. Growers in the district rely on these chemicals for *Helicoverpa* control as well as some organophosphates, spinosads and endosulfan. Resistance levels for these other chemicals were investigated in this project. Migration of *Helicoverpa* into fresh market tomato crops will have an impact on any resistance management strategy. The genetic basis of the *Helicoverpa armigera* population in the Goulburn valley region was examined using microsatellite analysis to determine the number of local moths and the number of immigrants.

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(Lepidoptera:Noctuidae) in Australia: What do we know*? Australian Journal of Zoology*. **34**, 779-814

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Section 1 Population Dynamics and Timing Chemical Applications

Introduction

It is important to understand the implications of pest management decisions to determine if methods could be adjusted to improve timing and efficiency of chemical applications. Crop monitoring is an essential element of IPM, providing information on pests and beneficials present in the crop. This information assists growers to evaluate the risks associated with these pests and make appropriate management decisions. Effective and timely pest control decisions can only be made with regular monitoring.

Populations of *Helicoverpa* have fluctuated over the previous 6 years. Weather conditions, in particular drought conditions, have impacted on the number of moths present and the survival of eggs and larvae. Drought conditions can affect the emergence of moths from the soil, moths may be unable to break through dry compacted soil and drought conditions can also cause desiccation of pupae. The effect of drought conditions on native flora may mean a lack of food sources for moths, particularly in the case of the native budworm *H. punctigera*. Temperatures above 35^{o}C can also reduce the survival, fertility and fecundity of the moth (Fitt 1989, Rochester 1999). Temperatures above 38^{o}C reduce egg survival with eggs desiccating at these temperatures (Rochester 1999).

Pheromone traps are often used to monitor *Helicoverpa* populations, however there are problems with using these traps. Pheromone traps attract only male moths and they have low catch efficiency (Fitt 1989). Pheromone trap catch studies have shown that trap sites are probably reflecting net fluxes of immigrants into the crops rather than a combination of local moths and immigrants (Fitt et al 1989). To effectively monitor *Helicoverpa* populations the egg stage needs to be monitored. Currently growers use a form of calendar spray program to time insecticide applications. These chemical programs often mean chemicals are being applied every 7 to 10 days regardless of pest abundance and crop growth stage. However the previous project (VG98150) also found that there were gaps in spray programs particularly over the December / January period of between 12 and 28 days. This is a busy time of the year for growers with late crops being planted and harvesting beginning on some of the early crops. This period is also when the highest oviposition occurs and because of the hot weather the lifecycle of *Helicoverpa* is shorter. Spray programs, where chemicals are applied every 7 to 10 days and are not based on the abundance of a pest can miss egg hatchings and chemicals may sometimes be unnecessarily sprayed on the crop. Large gaps in spray programs, in some cases in excess of twenty days also mean that egg hatchings can be missed. Over the summer higher temperatures mean that eggs hatch quicker and larvae quickly move under leaves or into fruit where they are protected.

For chemicals to be effective against a pest they should be applied at the most vulnerable life-stage of the pest. Ideally, *Helicoverpa* should be targeted at the egg stage or first instar larvae. Growers need to monitor their crops to see peaks in *Helicoverpa* oviposition and egg hatchings so they can target the vulnerable life-stages and spray only when action thresholds are exceeded. If growers are not monitoring their crops they will not be able to maximise the impact of their chemical applications.

There are a number of opportunities to improve current chemical applications and hence improve control of *Helicoverpa,* reduce fruit damage, and improve financial returns.

Methods

1. Egg Numbers

Crops were monitored from December to February and all monitoring results were reported to participating growers the day after monitoring the block. *Helicoverpa* egg numbers where monitored throughout the 2002-2003, 2003-2004 and 2004-2005 seasons using the following procedure. The blocks, approximately 8 acres, were monitored twice a week. Two trellis and three ground crops were monitored. To determine sites for monitoring, row numbers and sampling distance along the rows were decided using a random number generator. To determine sites for monitoring, row numbers and sampling distance along the rows were decided using a random number generator. There were twenty random sampling sites along each row and 6 rows were monitored. A total of 120 samples were monitored at each block. The first three fully expanded leaves were monitored for *Helicoverpa* eggs. In each season, later planted crops were monitored from December to February. Blocks were located in Undera, Murchison, Ardmona, Byrneside, and Harston. Data from the 2000-2001 and 2001-2002 season are also included.

2. Pheromone traps

Commercial pheromone traps (Funnel traps (Agrisense Pty. Ltd.) and Desire (HortResearch) lures) were placed around the Goulburn Valley Region and monitored once a week during the 2002-2003, 2003-2004 and 2004-2005 seasons. Between 5 and 7 traps for each species were placed on different properties around the region. Moth traps were collected weekly and the average trap catch calculated.

Pheromone trap data from Cranbourne and Werribee South and Bairnsdale for the 2004-2005 season were compared with trap catch data from the Goulburn Valley Region

3. Timing Chemical Application

Spray records collected from growers and dates of chemical application were compared with graphs of egg numbers to determine if the insecticide was timed to have maximum effect on peak egg lays.

4. Harvest Assessments

Harvest assessments occurred mid-late February. For each block 1200 fruit were assessed for *Helicoverpa* damage. Row numbers and sampling distance along the rows were decided using a random number generator. Twenty random sampling sites along each row were selected and 10 fruit, selected at random, were assessed at each site.

5. Chemicals used by the fresh market tomato industry

Chemical records were obtained from growers and compared to monitoring data and harvest assessments. Industry wide patterns of chemical use were also analysed.

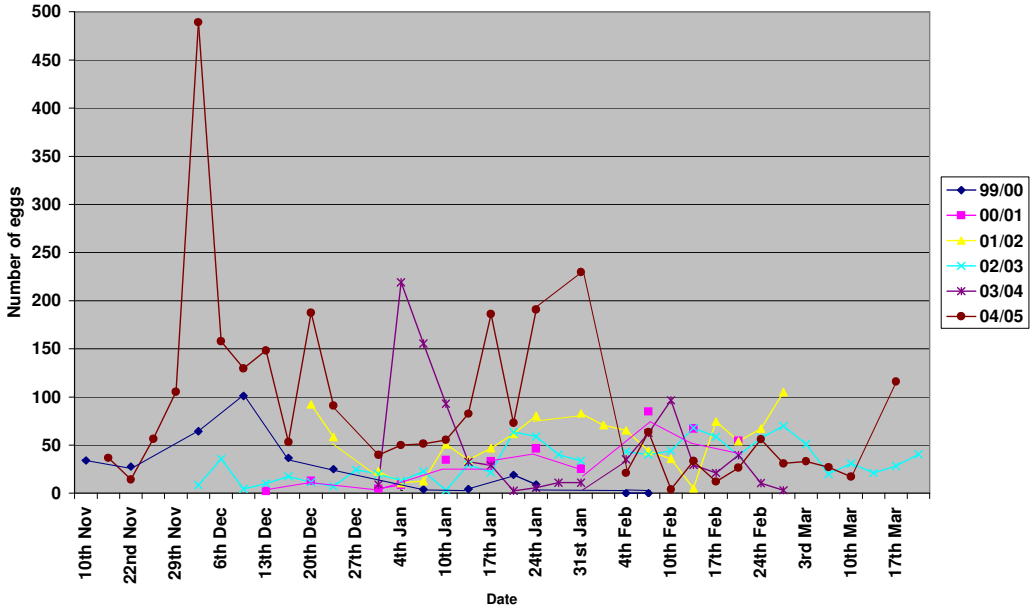
Results

1. Egg counts

Peaks in egg numbers vary from year to year both in number and the time of year when they occur

Fig 1 Average egg numbers per block for 5 seasons

At each sample date 120 sample sites/block were inspected for eggs. Data presented are averages over 6 blocks each year.



2. Pheromone trap catches

Fig 2.1 Helicoverpa armigera and Helicoverpa punctigera moths and eggs in the 2002-2003 season

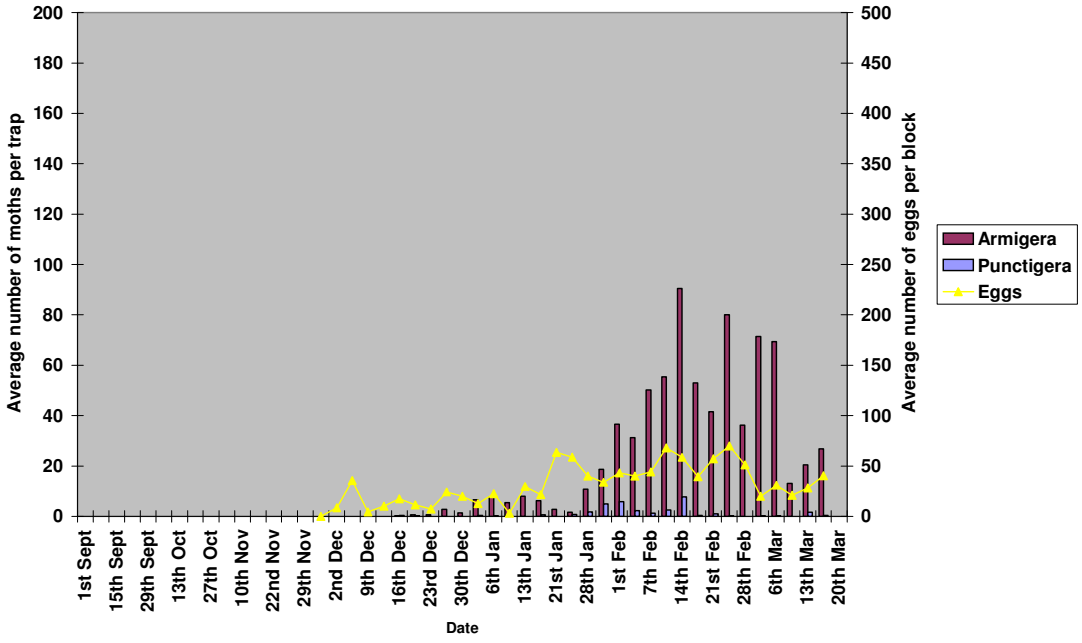


Fig 2.2 Helicoverpa armigera and Helicoverpa punctigera moths and eggs in the 2003-2004 season

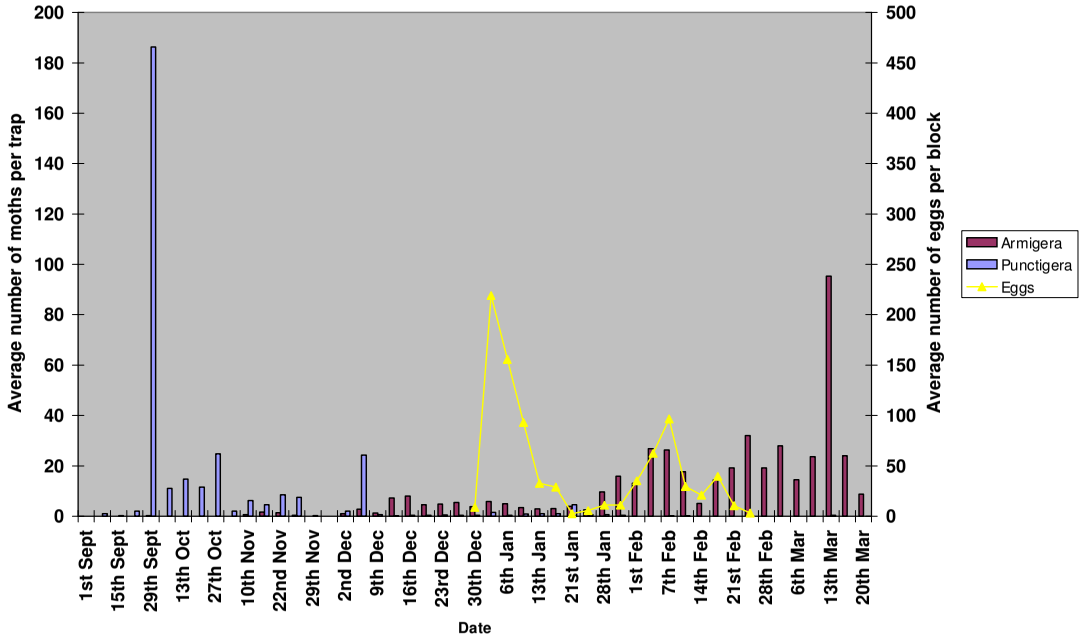
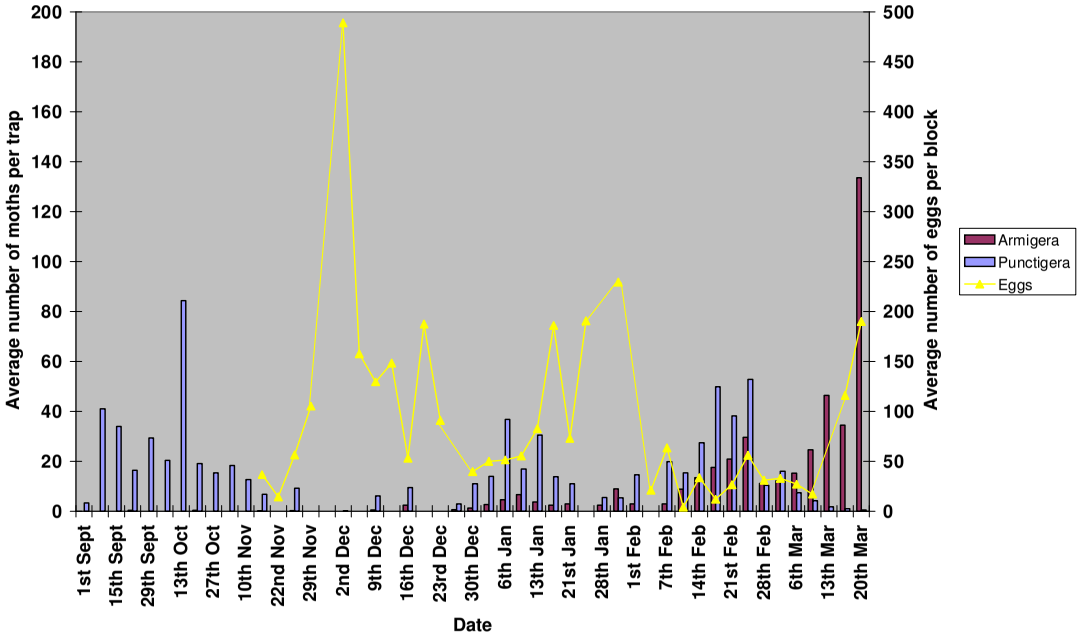


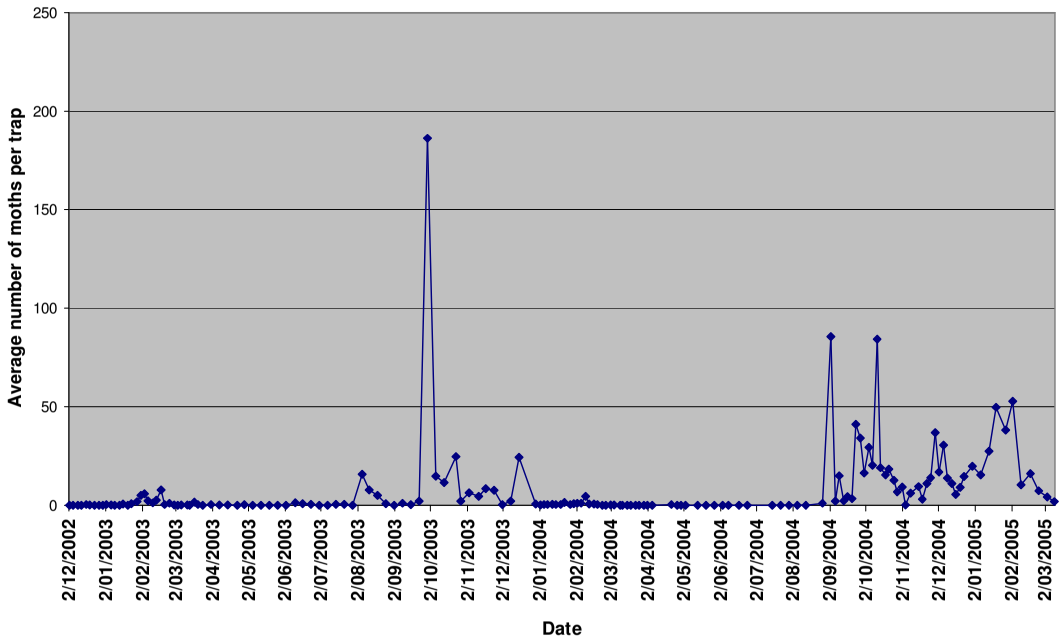
Fig 2.3 Helicoverpa armigera and Helicoverpa punctigera moths and eggs in the 2004-2005 season



Overall trends:

Peaks in *H. punctigera* moth numbers start late September/ early October through to late February, with the September / October peaks being the highest.

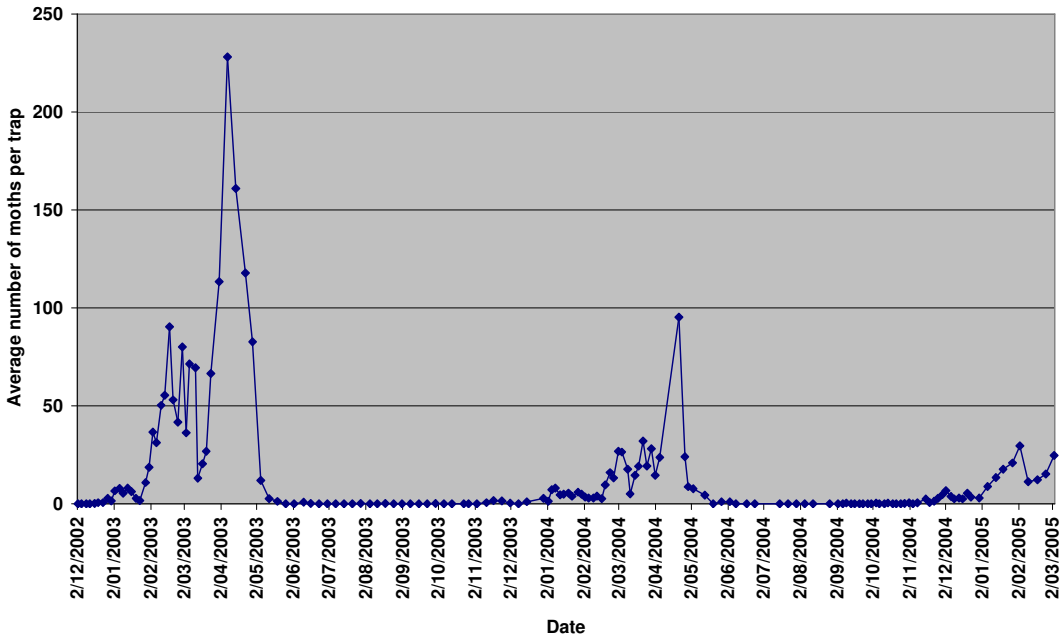
Fig 2.4 Average Helicoverpa punctigera moth numbers from December 2002 to March



2005

Peaks in *H. armigera* moth numbers start early February through to mid April, with the April peaks being the highest.

Fig 2.5 Average Helicoverpa armigera moth numbers from December 2002 to March 2005



Moth numbers in Tatura, Cranbourne, Werribee South and Bairnsdale:

Moth numbers for both species were considerably higher in the Tatura region than in Cranbourne, Werribee South or Bairnsdale.

Fig 2.6 Average moth trap numbers for Helicoverpa armigera in Tatura, Bairnsdale, Cranbourne and Werribee South for the period 2004-2005 season

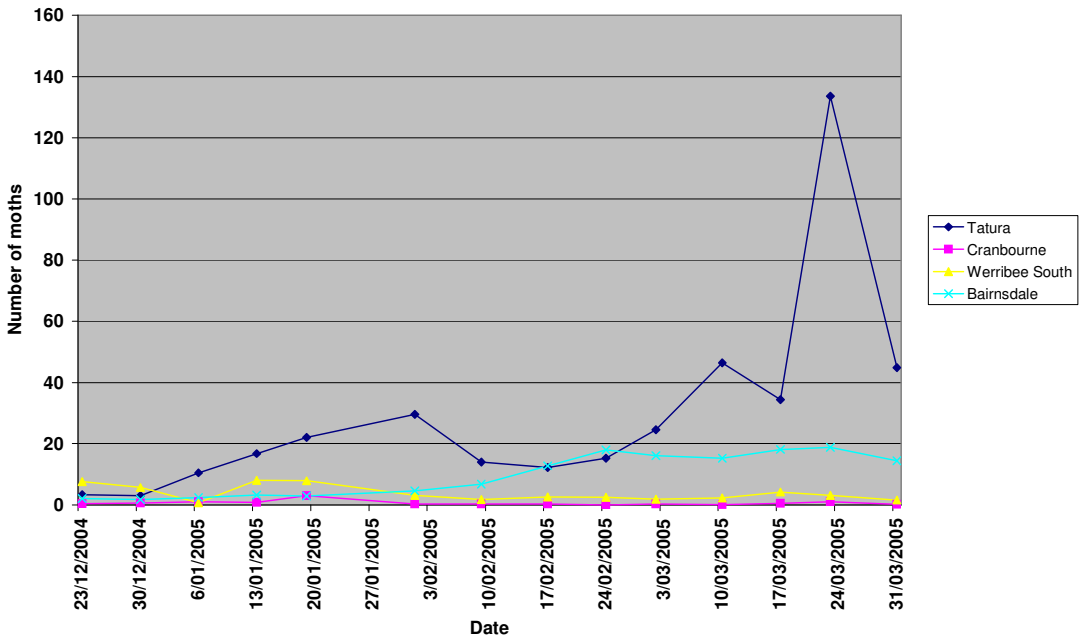
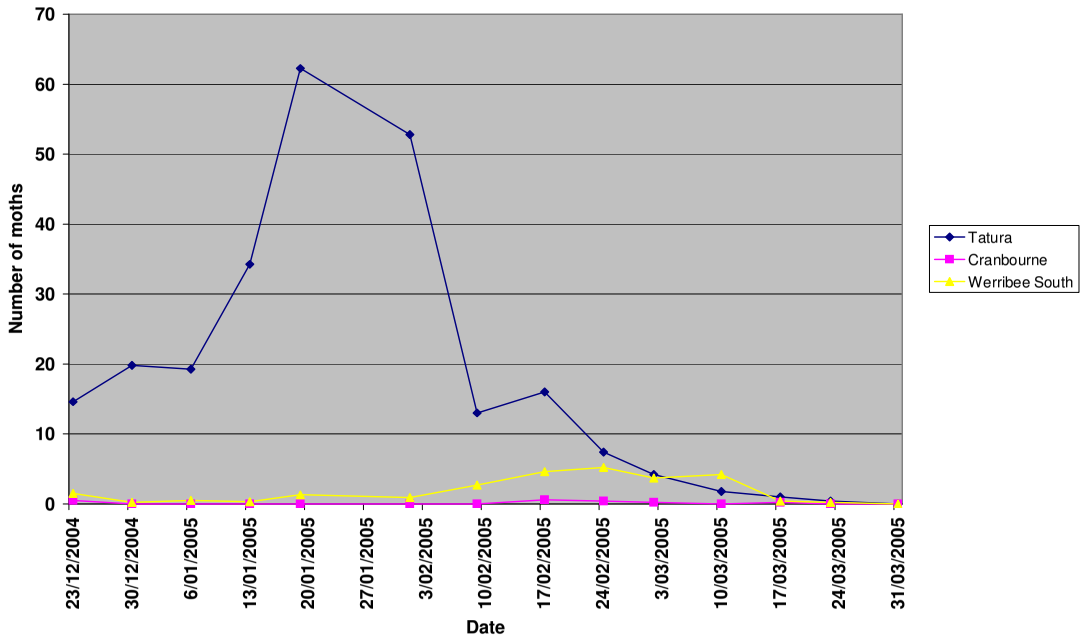


Fig 2.7 Average moth trap numbers for Helicoverpa punctigera in Tatura, Cranbourne and Werribee South for the period 2004-2005 season

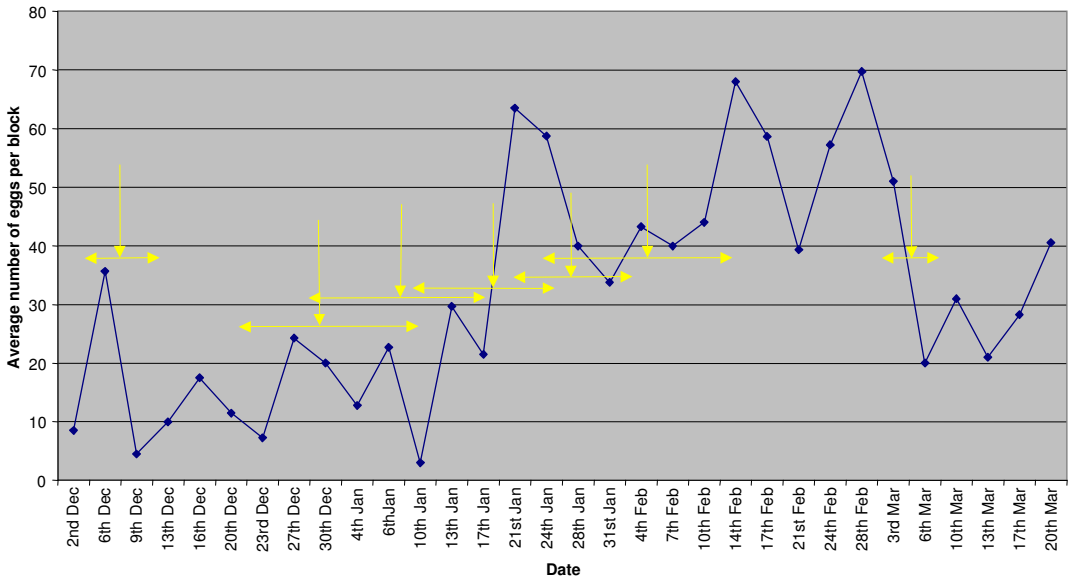


3. Timing Chemical Applications

Spray records often showed gaps in their spray programs, when peaks in egg numbers occurred.

During the December to February period intervals between chemical applications ranged from 4 day to 28 days in the 2000-2001, 2001-2002, 2002-2003 seasons. The graph below shows how several growers each using different spray programs can cause a considerable overlap in the application of chemical groups. The graph also shows that many applications would miss peak egg lays.

Fig 3.1 An example of mean Helicoverpa oviposition and insecticide application during a tomato season. Arrows indicate key insecticide application times, the vertical arrow indicate mean spray dates for each insecticide application and the horizontal arrow indicates the range of spray dates around the mean.



4. Harvest Assessments

Harvest assessments were conducted on 1200 fruit from each block starting from the second week of February. The number of blocks each year varied.

Table 4.1 Percentage of fruit damaged by Helicoverpa

	% Percentage fruit damage by Helicoverpa				
	2004/2005	**2003/2004**	**2002/2003**	**2001/2002**	**2000/2001**
Block 1	7.17	2.83	2.79	1.3	6.5
Block 2	12.04	2.3	0.75	0.25	2.42
Block 3	3	4.5	0.5	0.42	16.33
Block 4	1.5	0.83	2.25	1.67	8.08
Block 5	17.33			1.17	9.5
Block 6	2			0.83	
Block 7	3.92				
Block 8	5.75				
Block 9	2.33				
Block 10	13.3				
Average	**6.83**	**2.62**	**1.57**	**0.94**	**8.6**

5. Chemicals used by the fresh market tomato industry

Table 5.1 Insecticides used by the fresh market tomato industry – trade name, chemical group and chemical type

Insecticides	Group	Components	Chemical Type
Nudrin	1A	Methomyl	Carbamate
Larvin	1A	Thiodicarb	Carbamate
Electra	1A	Methomyl	Carbamate
Azodrin	1B	Monocrotophos	Organophosphate
Rogor	1B	Dimethoate	Organophosphate
Nitofol	1B	Methamidophos	Organophosphate
Orthene	1B	Acephate	Organophosphate
Lorsban	1B	Chlorpyrifos	Organophosphate
Endosulfan	2A	Endosulfan	Cyclodienes
Miti-fol	2B	Dicofol	Polychlorocycloalthanes
Kelthane	2B	Dicofol	Polychlorocycloalthanes
Scud	3A	Cypermethrin	Pyrethroid
Bulldock	3A	Beta-cyfluthrin	Pyrethroid
Sumi-Alpha	3A	Esfenvalerate	Pyrethroid
Hallmark	3A	Esfenvalerate	Pyrethroid
Fastac	3A	Alpha-cypermethrin	Pyrethroid
Ballistic	3A	Deltamethrin	Pyrethroid
Talstar	3A	Bifenthrin	Pyrethroid
Success	5A	Spinosad	Spinosyns
Vertimec	6A	Abamectin	Avermectin, Emamectin, Benzoate
Proclaim	6A	emamectin as benzoate	
BT	11		
Omite	14A	Propargite	Propargite
Prodigy	16A	methoxyfenozide	
Avatar	22A	Indoxacarb	Indoxacarb

Table 5.2 Chemicals used by growers in the 2000 – 2001 season

Helicoverpa Generations	Grower A	Grower B	Grower C	Grower D
1st Generation				
2nd Generation	1B	3A, 1B 3A, 1B	3A	5A, 1A
3rd Generation	2A 1B	3A, 1B 3A, 1B 1A, 3A, 1B, 2B 1B, 1A, 1B	3A, 1B 1B, 1A	5A 1B, 1A, 3A 1B, 1A, 3A 1B, 1A, 3A 1B, 1A
4th Generation	3A 3A 1A, 5A	1B, 1A, 1B 2B, 1B, 1A 1B, 3A, 1A 1B, 5A, 1A 1B, 1A, 5A	3A	1B, 1A 1B, 1A 1B, 1A, 3A 1B, 1A, 3A 1B, 1A, 3A
5th Generation	1A, 3A 3A		3A 1B	1B, 5A 1A, 3A
Harvest Assessment	8.1	9.5	16.33	6.5

Table 5.3 Chemicals used by growers in the 2001 – 2002 season

Helicoverpa Generations	Grower A	Grower B	Grower C	Grower E
1st Generation				
2nd Generation	1B 2A	1B, 3A	3A	
3rd Generation	3A 3A	1B, 3A 1B, 1A, 22A 3A 1B, 1A, 3A 1B, 1A, 3A	3A, 1B	1A, 1B 1A, 1B
4th Generation	5A 3A	1B, 1A, 5A 1B, 1A, 3A 22A 1B, 1A, 3A 1A, 3A	1B, 1A 3A	3A, 1A 3A, 1A 1B 1A, 1B
5th Generation	3A 3A 3A	3A 3A	3A 3A	
Harvest Assessment	1.7	0.25	1.3	0.42

Table 5.4 Chemicals used by growers in the 2002 – 2003 season

Helicoverpa Generations	Grower A	Grower C	Grower F	Grower G
1st Generation				
2nd Generation	3A 1B	1B	1B	1B 1B
3rd Generation	1B 3A, 1A	1B, 22A 1B, 5A	5A 5A 5A 5A 1A	1B 1B
4th Generation	1A, 3A 1A, 1B	1B 22A	1A	2B
5th Generation	1A, 3A 1A 3A		5A	2B
Harvest Assessment	2.8	2.25	3.1	6

Discussion

There are usually five generations of *Helicoverpa* in this region over the season. Discrete generations of *Helicoverpa* are not always clear and considerable overlap can occur after the first spring generation.

The time period of peaks in egg numbers, the duration of egg peaks and the size of egg peaks have varied from year to year. Egg peaks in the 2003/2004 and 2004/2005 seasons were considerably higher than in previous years. However, egg numbers were lower in 2003/2004 compared to the same period in the 2004-2005 season (865.5 in 2003/2004 and 1205.75 in 2004/2005). Peaks in egg numbers in the 2003/2004 season occurred early January and early February. A peak in egg numbers for the 2004/2005 season occurred mid– late January, with smaller peaks early and late February. Egg numbers in the 2004/2005 season were very high with 10,162 eggs collected during monitoring compared to 4090 over the same period in the 2002-2003 season. Drought conditions may have had a significant impact on egg numbers.

There seems to be very little correlation between the trap counts and egg numbers. There was also considerable variation in the number of moths found in each trap around the district. Kumar (2003) found that it is difficult to use trap catches as indices of moth densities and trap catches can vary even across small distances. While trap catches may give an indication of activity and migration events they cannot reliably be used to predict peaks in egg numbers.

Typically, the spray records of participating growers indicate that chemicals have not been applied to align with critical oviposition periods. Harvest assessments show a large variation in damage to crops. Looking at the spray records, egg counts and resulting damage it is clear that the current calendar spraying approach means that some chemicals miss peak egg lays and have very little affect on the population and others hit peak egg lays and significantly reduce the population. This approach to chemical application puts the crop at considerable risk of damage. Long gaps in chemical application are also evident particularly during the December / January period. Gaps that appear in spray programs over the December /January period seem to correlate with activities such as harvesting early crops, planting late crops and pruning / trellising of crops. During this busy period these factors rather than pest abundance seem to influence when insecticides are applied. These gaps also coincide with high oviposition and a shorter development time for *Helicoverpa* due to the hot weather. Fluctuating temperatures have been shown to speed up development times in *H. armigera* (Zalucki et al 1986). As *Helicoverpa* larvae develop they enter the tomato plant or fruit where they are protected from chemical applications. In summer eggs can be laid, then hatch and the larvae can be protected inside the plant within 7 days. Based on current chemical spray programs this could all happen between insecticide applications. Long gaps in the spray program are fine if very few eggs are being laid however if there are peaks in oviposition during this time they can develop unhindered and cause fruit damage. Large larvae (over 2cm) are often very visible in the crop. However once larvae reach this size they have already done considerable damage to the crop. Crops harvested in mid-February to mid-March (planted in December/early January) sustain heavier damage from *Helicoverpa* than crops harvested earlier or later than this. This is due to the short development time of *Helicoverpa* over this period and failure to

time the chemical applications to the vulnerable life-stages of *Helicoverpa* so that the maximum effect of a chemical can be achieved.

Another factor complicating this is the development of resistance, which is affecting the efficacy of some chemicals. An increasing level of resistance in some chemicals means that, regardless of spray timing, a large proportion of the population will remain unaffected. Each grower sprays to a chemical program and our results show that there is considerable overlap of the chemicals being applied. This overlap in chemical applications can potentially increase resistance problems, as *Helicoverpa* migrating locally over short distances will be exposed to multiple applications. There is also a large variation in the number of insecticides being applied to the crop and the same chemical groups being used several times over more than one generation will also increase insecticide resistance.

Very low populations of *Helicoverpa* in some years due to unfavourable conditions have seen little reduction in the number of sprays applied for the control of *Helicoverpa*. Calendar spray programs do not relate to pest abundance and therefore the likelihood of unnecessary sprays being applied under these conditions is very high.

Our data shows that *Helicoverpa* eggs will hatch and the larvae will be protected inside the plant before the critical sprays are applied. Monitoring the crop and applying chemicals based on the results of that monitoring could reduce fruit damage. Monitoring the crop means informed decisions could be made based on the presence and abundance of pests and beneficials. With resistance levels already high for some insecticides there is a growing risk of field failure of chemical applications due to resistance. Monitoring crops will also allow growers to ascertain the effectiveness of their chemical applications.

No attempt was made to relate either moth numbers or egg numbers to damage and thereby determine an action threshold. HAL and NVFTIDC specifically directed that thresholds were not to be addressed as part of this project. However the use of thresholds is discussed in section 6 Resistance Management.

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Section 2 Migration of *Helicoverpa* – Microsatellite Analysis

Introduction

The previous project (VG98150) showed that there is a possibility that *Helicoverpa* moths from other districts may be migrating to tomato growing areas. For IPM strategies to be effective, we need to understand the migration of *Helicoverpa*, the dynamics of the local population and the seasonal shifts in populations in the northern Victorian fresh tomato growing district. The genetics and potential resistance of *Helicoverpa* populations may vary from one region to another, and it is essential to determine whether it is local populations or immigrant moths that are to be targeted by control strategies.

The University of Queensland (UQ) are currently using microsatellite DNA technologies to determine the genetic variation between individual insects and populations of *Helicoverpa*. The project utilised the services of the UQ to further understand the population structure of our local *Helicoverpa* and migrating moths from northern districts.

Microsatellites are simple sequence tandem repeats (SSTRs), short DNA sequences in which the nucleotides repeat themselves. Quantification of variation in these repeated microsatellite sequences can be used to determine relatedness between individuals. Microsatellites are useful genetic markers because they tend to be highly polymorphic. Microsatellite polymorphisms have become very popular because; tiny quantities of DNA are used, alleles can be read very reliably, there are very large numbers of polymorphic loci, often there are large numbers of alleles, so that the markers are highly informative and automated techniques such as PCR can be used.

UQ has constructed a microsatellite library for *Helicoverpa armigera*. This library was used to investigate shifts in different population structures along multiple growing seasons, within different regions and on different crops. The proportion of migrant moths is worked out using microsatellite alleles which are specific to specific regions (ie/ Goulburn Valley region). Genetic estimates are based on these alleles. Migrants are the number of moths that do not have these alleles.

Methods

Dr Kirsten Scott at UQ is currently using microsatellite DNA technologies to determine the genetic variation between individual insects and populations of *Helicoverpa armigera*..

Helicoverpa armigera moths were collected from the Bairnsdale, Werribee and the Goulburn Valley regions of Victoria. Sampling was over a 15 month period (January 2003 to March 2004). Due to variation in pest pressure, the number of samples obtained each month varied over the year. Moths were collected from pheromone traps and each sample was placed in ethanol, samples were then couriered to UQ.

Dr Scott extracted DNA for microsatellite analysis from individual moth heads or larval posterior prolegs using a 96-well modification of the Miller *et al*. (1988) protocol. The remaining insect was stored individually in an ethanol vial, and cross referenced to the DNA extraction. A diagnostic PCR (developed by UQ) was then utilised to determine if each individual was either *H. armigera* or *H. punctigera*. The species diagnostic ensured microsatellite analysis was performed on *H. armigera*

individuals only, as morphological determination of species after storage in ethanol can be problematic. A total of 710 *H. armigera* individuals were analysed from 54 collections consisting of 12 geographic locations and multiple collection dates (Table 1). Some variation occurred in the number of individuals analysed per collection due to differing proportions of *H. armigera* and *H. punctigera* present in the samples taken at each location.

Microsatellite analysis

Microsatellites were selected as the marker system in this study, as they covered multiple loci, were economic for large scale studies, transferable to other *Helicoverpa*, were co-dominant and highly polymorphic, suiting them well to the task of measuring genetic structure in *H. armigera* in Australia. Five microsatellite loci (170 alleles) were used to analyse the 710 *H. armigera* individuals. The loci were HaB60, HaD25, HaD47, HaC87 and HaC14 (Centre for Identification and Diagnostics, unpublished: for primer sequences please contact the authors). The microsatellite amplification conditions were as follows: 25 ng DNA, 1.5 mM $MgCl_2$, 0.2 μM of each primer (forward primer labeled with Hex), 20 mM Tris-HCl, 100 mM KCl, 1 unit of *Taq* polymerase (Qiagen, Clifton Hill, Vic.) and 0.2 mM of dNTPs (Amrad/Biotech, Boronia, Vic.) in a 20 μL reaction volume. Cycling conditions in a Corbett Research PC960 Thermal Cycler (Corbett Research, Mortlake, NSW) were 94°C for 1 min, 50°C for 1 min, 73°C for 1 min for 35 cycles. Microsatellite scoring was on a 7% native acrylamide gel (as per Corbett Research GS2000 manual) in a Corbett Research GS2000 Genetic Analyser.

Statistical analysis

Microsatellite alleles were scored using ONE-Dscan (Ver 1.33, Scanalytics Inc., Billerica, MA). Allele sizes were entered into Excel (Microsoft Corp., North Ryde, NSW) and analysed using GenAlEx (Peakall and Smouse 2001). Nei distance between collections was calculated using Weir (1990), and pairwise genetic distances were calculated as in Peakall *et al.* (1995). Allele frequencies and heterozygosity calculations followed the formulae of Hartl and Clark (1997). N*m* was estimated using the private allele method of Slatkin (1985) and Slatkin and Barton (1989). Analysis of Molecular Variance (AMOVA) was as for Excoffier *et al.* (1992), Peakall *et al.* (1995) and Michalakis and Excoffier (1996). Principle co-ordinate analysis used the algorithm published by Orloci (1978).

Results

Table 1. Analysis of Molecular variance (AMOVA) results for Victoria from January 2003 to March 2004. A collection constitutes a single sampling event at a locality on a single day. *p* for % difference = 0.001 unless stated. Timeframe groups created where there is no significant difference by AMOVA

Timeframes compared		% Difference between timeframes (p)	% Difference between collections (p)	% Difference within collections (p)
Jan03	**Feb03-May03**	15	19	66
Feb03-May03	**Dec03**	16	15	69
Dec03	**Jan04-Feb04**	4	16	80
Jan04-Feb04	**Mar04**	6	20	74

Table 2. Assignment of Victorian migrants identified using Monte-Carlo re-sampling of gametes (Paetkau et al 2004) in GeneClass 2.3 (Piry et al unpublished).

				% Assigned			
Victorian collections	**n**	**n unassigned**	**Victoria**	**Murrumbidgee Valley**	**Darling Downs**	**Macintyre Valley**	**Source Unknown**
Jan 2003	104	39	70.8	21.5	3.1	1.5	3.1
Feb-May 2003	108	1	70.1	21.5			8.4
Dec-Feb 2004	126	27	79.8	20.2			0

The following shows the percentage of variation between one discrete timeframe (group) and the next:

Discrete timeframes:

January 2003 15%

February 2003 – May 2003 16%

December 2004 4%

January 2004 –February 2004 6%

March 2004

These groups are those that separated as distinct using the AMOVA test.

Discussion

There were changes in the genetic structuring of *H. armigera* populations from the Goulburn Valley region over time.

The percentage of moths assigned as being local, is around 70% to 80%. The 'local' moths over-winter in the Goulburn Valley region, with immigrant moths coming from outside this region. The number of immigrant moths is between 20% and 30%. Immigrants have been assigned predominantly to the Murrumbidgee Valley (approx. 20%) with smaller amounts coming from Qld and northern NSW. Between 3% and 8.4% of individuals are from unknown origins.

Migration of moths from other regions and the selection pressure that insecticides put pests under can impact on the resistant levels in a region. Low levels of migration can increase or reduce the accumulation of resistance to insecticides (Korman et al 1993). Low levels of migration can reduce the speed and likelihood of the movement of resistant moths to new areas; however, low migration will also mean that if resistance is accumulating, there will be no dilution of this accumulation by susceptible moths immigrating from other areas (Korman et al 1993). High migration can either increase resistance due to a large number of resistant moths moving into the region or decrease it due to a large number of susceptible moths moving into the region.

Levels of migration into this region may vary from month to month in any given year and from year to year. There was a small amount of genetic variation in *H. armigera* moth populations in the Goulburn Valley region between January 2003 and March 2004. There was no variation in the genetic structure of moth populations between February 2004 and March 2004.

It should also be noted that this study looked only at the long distance migration of moths but local migration of this pest is also important. Local movements within tomato crops and between nearby tomato crops, alternative hosts and wild hosts are also important in the seasonal dynamics of this pest especially in diverse cropping systems (such as the Goulburn Valley Region) where feeding and oviposition sites may be continuously available (Fitt 1989). Both long distance and local migration can make resistance management difficult unless resistance management strategies are implemented on a regional scale.

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Section 3 Fruit Damage – Which *Helicoverpa* species is causing the damage?

Introduction

Helicoverpa punctigera is thought to be the dominant species in spring and early summer and *Helicoverpa armigera* the dominant species from December onwards. Crops planted in December are under the greatest pressure from *Helicoverpa* and have the greatest damage at harvest, which is in mid to late February.

The reason for large amounts of fruit damage at this time of year is sometimes put down to the difficulty in controlling *H. armigera* due to the resistance it has developed to a number of insecticides. Whilst *H. punctigera* has developed some resistance to some insecticides it is much more susceptible to insecticides than *H. armigera.*

This study investigated which species was causing the most fruit damage.

Methods

Larvae were collected from fruit in February and March between 2003-2005. Small larvae were reared on artificial diet until they reached 6th instar stage. The 6th instar stage was determined by the size of the larvae.

Larvae were identified to species by the colour of the dorsal anterior cervical shield hairs. These are white in *H. armigera* and black in *H. punctigera* (Zalucki et al 1986).

Results

% of fruit damaged by *H. punctigera* and *H. armigera* in the 2003/2004 and 2004/2005 seasons

	% of fruit damage			
	2003/2004 (n=155)		2004/2005 (n=400)	
Time	***Punctigera***	***Armigera***	***Punctigera***	***Armigera***
February	81	19	18	82
March	45	55	6	94
Overall	68	32	12	88

Discussion

Despite the commonly held belief that *Helicoverpa armigera* is the important species in crop damage late summer the results from the 2003/2004 season show a large proportion of the larvae collected from damaged fruit were *Helicoverpa punctigera*. This changed the following year, 2004/2005, when a large proportion of the fruit damage was caused by *H. armigera.*

Helicoverpa punctigera has a much more complex diapause strategy than *Helicoverpa armigera*. *H. punctigera* has developed a diapause strategy and movement which takes advantage of a highly unpredictable environment (Fitt, 1989).

In eastern Australia many pupae enter a winter diapause but some survive winter without diapausing, emerging before the bulk of the population. A portion of the first generation may then enter a spring diapause, adults emerging early summer (Cullen et al 1978). Some will diapause in summer, emerging late summer or early autumn (Fitt 1989). This diapausing strategy ensures that some of the population will survive unfavourable weather conditions, and allows the species to take advantage of suitable conditions at other times of the year. This may help explain why in the 2003/2004 season the majority of fruit damage in late summer / early autumn was caused by *H. punctigera*.

These results show that either species could be responsible for the majority of fruit damage. While resistance levels are increasing in both species, resistance is much lower in punctigera therefore resistance cannot be the only factor affecting the ability to control *Helicoverpa* at this critical time of the year. Other factors can also increase the amount of damage, factors such as timing insecticides to get the maximum benefit out of that chemical.

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Section 4 Effect of Nitrogen on the Oviposition preference of *Helicoverpa*

Introduction

There is a heavy reliance on the use of insecticides to control *Helicoverpa*, but with increasing resistance levels and a medium to high percentage of fruit damage in most years alternative strategies are needed.

Plants can have both intrinsic (direct) defences, as well as extrinsic (indirect) defenses against herbivores and pathogens and these defences can be affected by plant nutrition and other environmental factors (Bernays & Chapman 1994). Chemical cues (volatile and/or surface chemicals) are known to be involved in the oviposition behaviour of some *Helicoverpa* spp. (Pophof et al. 2005, Tingle & Mitchell 1984, Ramaswamy et al. 1987, Jallow 1999, Flath, et al. 1978). Understanding the host selection behaviour of female moths and the responses to various chemical cues can provide information needed to develop alternative management strategies. Alternative strategies such as trap plants and attractants could potentially take advantage of host selection behaviour and responses to chemical cues.

Olson et al 1999, has observed that higher nitrogen in cotton plants results in higher levels of damage by *Helicoverpa zea* and *Heliothis virescens*. It is not known what mechanisms are behind this preference for higher nitrogen plants, it could be chemical volatiles or because plants are taller in higher nitrogen plots. Several Lepidopteran species are known to prefer taller plants for oviposition.

This section reports on a study to determine what influence, if any, that nitrogen has on the ovipositional behaviour of *Helicoverpa* moths. The experiment was designed to test if tomato plants with high nitrogen would result in higher oviposition by *Helicoverpa* moths.

Materials and Methods

Three treatments (Low, Standard and High Nitrogen) were replicated twice in a glasshouse with separate internal compartments. Each plot consisted of 15 potted tomato plants on a glasshouse bench. Plastic sheets suspended from the ceiling separated benches. A 40cm pedestal fan was placed at the end of each bench to provide a low velocity air stream moving over the plants toward the moth release site.

A laboratory strain of moths was used to ensure sufficient numbers of moths were available. Virgin moths were placed in moth cages and allowed to mate. Moths were allowed to begin laying eggs before the trial began.

Growing and nitrogen treatment of tomato plants:
Seedlings sourced from a local grower were transplanted to pots containing general purpose potting mix when six weeks old. The cultivar used was Red Ruby. The seedlings were grown in a glasshouse with daytime temperatures of 24°C to 31° C and night time temperatures of 21°C.

Plantastic-Grow[1], a product for hydroponically grown vegetables was applied to the plants at rates designed to give the desired N levels, for 8 weeks after transplanting.

		Total N per application
Treatment 1	Low	0.047g
Treatment 2	Standard	0.095g
Treatment 3	High	0.190g

Plantastic parts were mixed in four litres of water (As recommended firstly part A was added into water, then part B was added). The solutions of treatment 1, 2 and 3 were applied at a rate of 50 ml to each pot with a beaker twice a week. Fertiliser was applied after irrigation to prevent fertiliser leaching from the pots.

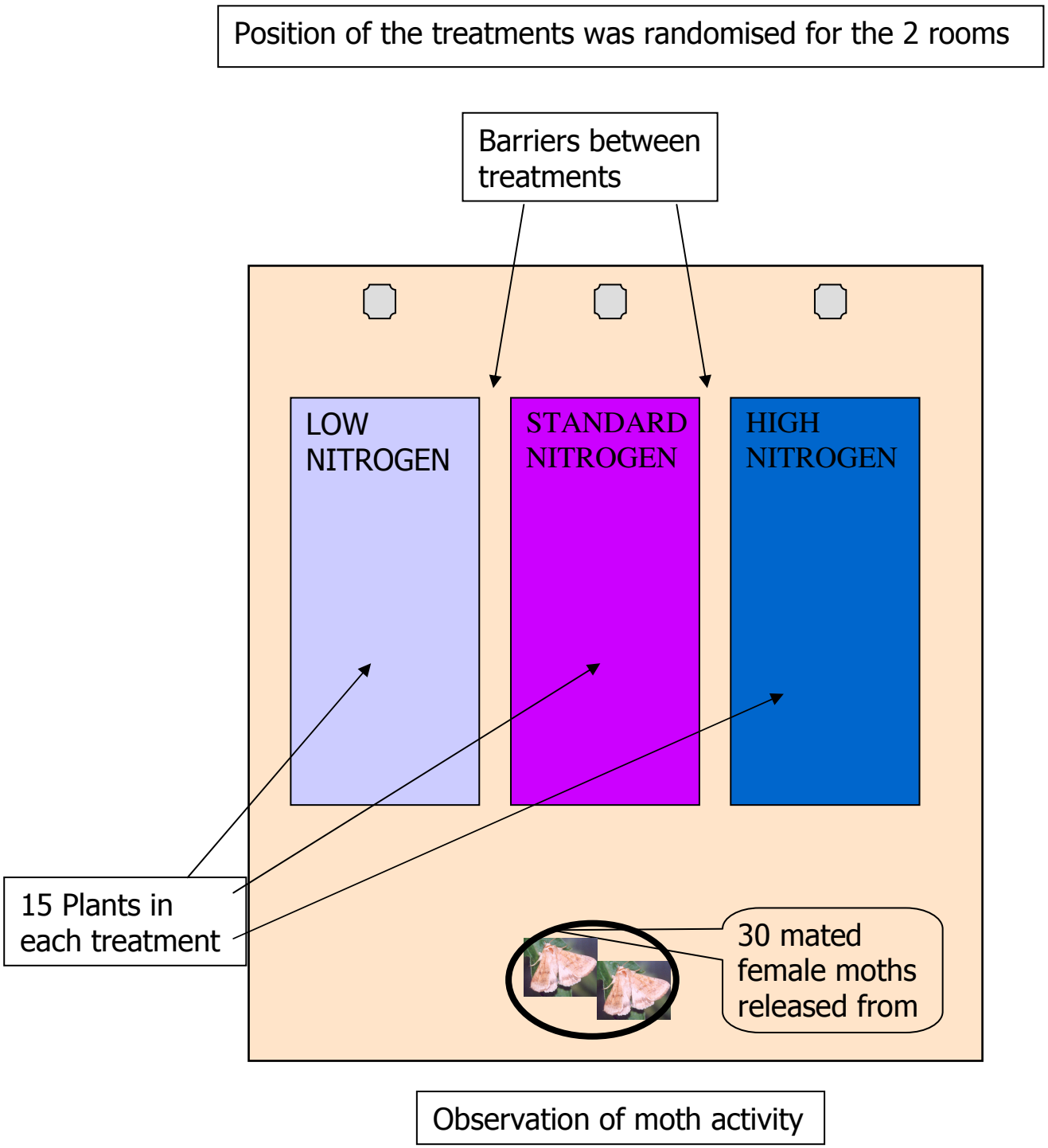
				Treatment 1 Plantastic ml/4lt		Treatment 2 Plantastic ml/4lt		Treatment 3 Plantastic ml/4lt	
	Week	Date	Day	PART A	PART B	PART A	PART B	PART A	PART B
Planting	1	13-Dec	Monday	5	5	15	15	30	30
Application 2	1	16-Dec	Thursday	5	5	15	15	30	30
Application 3	2	20-Dec	Monday	5	5	15	15	30	30
Application 4	2	23-Dec	Thursday	5	5	15	15	30	30
Application 5	3	27-Dec	Monday	5	5	15	15	30	30
Application 6	3	30-Dec	Thursday	5	5	15	15	30	30
Application 7	4	03-Jan	Monday	5	5	15	15	30	30
Application 8	4	06-Jan	Thursday	5	5	15	15	30	30
Application 9	5	10-Jan	Monday	5	5	15	15	30	30

Plants were individually watered by hand with a hose-mounted sprayer once or twice per day, to maintain the potting mix in moist conditions.

[1] Plantastic includes two part solutions, A and B with same amount of nutrients. Plantastic's recommended rate for the seedlings is 15 ml each from Part A and B, which was the control treatment in the trial.

Release of the Moths

At dusk a cage containing 30 mated female moths was placed about 2m in front of the treatment tables and opened releasing the moths. Moths were allowed to fly freely within each glasshouse.


Position of the treatments was randomised for the 2 rooms
Barriers between treatments
LOW NITROGEN
STANDARD NITROGEN
HIGH NITROGEN
15 Plants in each treatment
30 mated female moths released from
Observation of moth activity
Fans
Air-conditioning (turned off when moths go in)

Assessment:
Plant height measurement and number of open flowers were documented to indicate the stage of plant maturity. The assessment took place 3 days after the moths were released. Egg numbers were counted for each plant in each treatment, also the number of compound leaves, flowers and fruit for each plant. Plants were then destructively sampled for eggs – to obtain total number of eggs per plant. After this, each plant was weighed, given an individual sample number and bagged for drying, prior to nutrient analysis.
Four sub-samples per treatment were sent for analysis of nutrient contents by the state chemical laboratories.

Results / Discussion

The moths seemed to be more attracted to the window than to the tomato plants. The experiments were conducted at dusk and the windows provided the only light source. A possible reason for this was the laboratory culture used had been in culture for a year (several *Helicoverpa* generations) and may not have behaved the same as wild moths.

Only a very small number of eggs were laid on the plants (<50 eggs in both rooms), and most of this was on the plants near the window.

It was not possible to collect sufficient wild moths of known age/maturity status or to eliminate the influence of light from the window at dusk, so we decided to abandon further attempts. DPI Tatura has recently established a chemical ecology laboratory containing an electroantennogram (EAG). Once the EAG is fully functional we intend testing the response of moth antennae to volatiles collected from tomato plants of different N status.

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Section 5 Sampling Plan for *Helicoverpa*

Introduction

Currently, chemical applications in the fresh market tomato industry are based on calendar spraying programs, whereby pesticides are applied every 7– 10 days. Such programs can result in the unnecessary application of chemicals (Nilakhe *et al.* 1982, Hamilton & Macdonald 1990). Eggs may also hatch in between sprays and the resulting larvae can then move into the fruit. Therefore, it is important to monitor eggs regularly. To do this requires a monitoring system that is practical: a system that is easily implemented and is not time-consuming for growers. Sequential sampling plans are less time-consuming than other monitoring methods, particularly if pest populations are well above or below the threshold (Hoffman *et al.* 1991).

An understanding of the spatial distribution of a pest is needed when developing sampling plans to estimate pest population densities. Here we use the spatial distribution of *Helicoverpa* eggs in fresh market tomato crops to construct a sequential sampling plan.

Methods

Data collection

Two sets of data were collected. One set was used to construct the sampling plan (10/11/99 to 28/2/02) and describe the spatial distribution, and the other independent set was used for validating the sampling plan (2/12/02 to 20/3/03). The former comprised 149 field-dates (a field surveyed on a particular date) and the latter 140 field-dates. Data were collected from fresh-market tomato fields in the Goulburn Valley region of Victoria between December and February (summer) over four years, 1999 to 2003, according to the following procedure. At each field, six rows were selected at random (using a random number generator) and 120 plants were sampled, 20 plants in each row. For the first year of monitoring the distance between plants sampled in each row was 20 m. In the next three years the distance between plants sampled was determined using random numbers. The length of the row was used to define the range for the random number generator. The first 20 numbers in this range were then used for the distance between samples, representing the number of steps taken between each sample.

Plants were sampled for *Helicoverpa* by counting the eggs on the first three fully expanded compound leaves. This was used as the sampling unit because the highest concentration of *Helicoverpa* eggs has been found in these leaves (unpublished data, Mansfield & Dawson). Others have also found that the highest concentration of eggs is in the upper third of the plant (Nilakhe *et al.* 1982, Hamilton & Macdonald 1990, Duffield & Chapple 2001, Hassan *et al.* 1980), which is where the first three fully expanded compound leaves are found.

The tomato fields monitored were approximately 3.2 ha (8 acres). Trellis and ground tomatoes were monitored in the same way. Most of the industry uses trellis but there are still some ground crops, so both were represented here.

Nineteen crops were monitored over the four years (3 crops in the 1st year, 6 in the 2nd year, 6 in the 3rd year and 4 in the 4th year). For the first two years monitoring

occurred on a weekly basis and for the next two years it was twice weekly. Farmers maintained normal spray practices throughout the period of data collection.

Spatial distribution

We used Taylor's Power Law (TPL) (Taylor 1961) to model the variance-mean relation of the population. This law states that:

$$s^2 = a\bar{x}^b \quad (1)$$

where s^2 and $\bar{x}$ are the sample variance and sample mean respectively, a is a scaling factor that is dependent on sampling method and habitat, and the exponent b is a measure of aggregation. If b equals 1, then the population has a random distribution. When $b > 1$ the population is contagious (aggregated), and when $b < 1$ the population has a regular distribution.

Taylor's a and b parameters were estimated (i.e. $\hat{a}$ and $\hat{b}$) by regressing $\log_{10}$ variance against $\log_{10}$ mean. Since there was error associated with estimating both variables, a Reduced Major Axis regression method (also known as geometric mean regression) was used (computed using the *RMA* program, Bohonak 2002).

To make inferences about the spatial distribution of the species, we tested the null hypothesis that the slope was not significantly different from 1 by considering the 99% confidence intervals (CI_{99}) associated with the slope parameter. These confidence intervals would encompass 1 for a population that does not depart significantly from the Poisson distribution. There were two singleton observations (i.e. observations where larvae were only observed on one plant), and these were excluded from all analyses, since the values of s^2 and $\bar{x}$ are restricted in such circumstances ($\because s^2 = \bar{x}$), which leads to pseudo-randomness (Taylor 1984).

In addition to fitting TPL to the data-set described above, we also applied it to each year's data independently (i.e. all four years) to check if the spatial distribution of the species remained consistent over time. We did not divide the temporal scale further as all samples were collected around the same time of the year, i.e. summer.

Sampling plan

The minimum sample size (n_{min}) for Green's (1970) plan was calculated as:

$$n_{\min} = s^2 \big/ (D\,\bar{x})^2 \quad (1)$$

where D is the nominal (desired) level of precision, expressed in terms of the standard error as a fraction of the mean. The sequential sampling stop-line (T_n) was calculated as:

$$T_n = \left(\frac{D^2}{\hat{a}} \right)^{1/(\hat{b}-2)} n_{\min}^{(\hat{b}-1)/(\hat{b}-2)} \quad (2)$$

where $\hat{a}$ and $\hat{b}$ are the TPL regression parameters, estimated as described above.

Insufficient computing power was available to resample the large data set without replacement, so re-sampling with replacement (Naranjo & Hutchison, 1997) was used to validate the plan. The mean, minimum, and maximum levels of precision achieved over 1 000 iterations were plotted and compared to the nominal precision level. Similarly, the number of samples needed to satisfy the sequential stop rule over the 1 000 simulations was plotted. Because of the very large sample sizes demanded by the higher precision plans, it is highly unlikely that they would be used in practice, and thus only the D = 0.3 plan was presented and validated. This level of precision was suggested by Southwood (1978) as being appropriate for routine monitoring programmes for arthropod pests, and has subsequently been adopted by many (Barney & Legg 1988, Hutchison *et al.* 1988, Schulthess *et al.* 1989, Pringle & Giliomee 1992, Coffelt & Schultz 1994, Badenhausser 1996, Garat *et al.* 1999, Shah *et al.* 2000, Hamilton & Hepworth 2004). A minimum sample size of 10 plants was set, but all simulations used more than 10 samples.

Results

Spatial distribution

Taylor's Power Law described the variance-mean relation well (r^2 = 0.848) (Figure 1). The slope parameter of the fitted model was significantly greater than unity, indicating a contagious distribution (b = 1.590 [SE = 0.051]; lower and upper CI_{99} = 1.456, 1.724; df =148). The slope parameter was also stable across the years of the study (Table 1). For each year the CI_{99} around b encompassed the b value of 1.59 used to construct the plan, thus implying no significant year effect. The slopes were significantly greater than one for each year and each property, as evidenced by the fact that the lower CI_{99} was always above one.

Figure 1. Taylor's Power Plot for *Helicoverpa* on fresh market tomatoes. The fitted model is a reduced major axis regression.

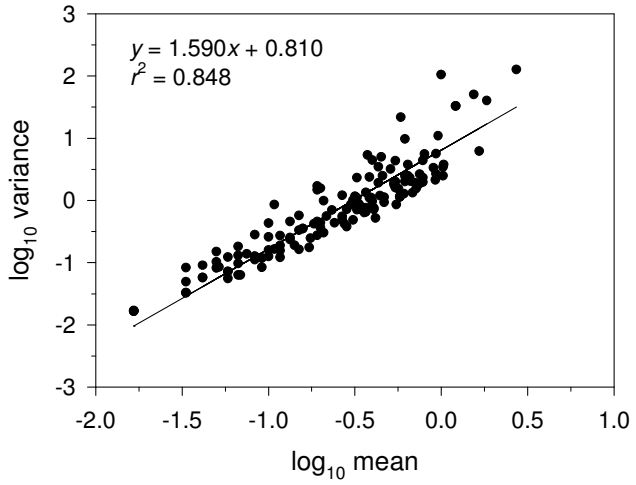


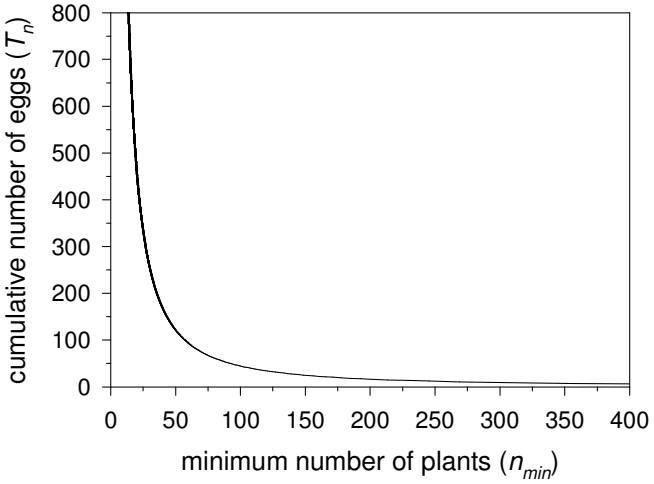
Table 1. Estimates of the slope parameter, *b*, of Taylor's Power Law (and associated standard error, s.e., and 99% confidence intervals, CI95) fitted to data-sets for each summer and each property. *n* is the sample size.

Summer	*b*	s.e.	CI_{99}	*n*
99–00	1.594	0.127	1.269–1.907	28
00–01	1.454	0.143	1.188–1.964	29
01–02	1.642	0.095	1.427–1.877	92
02–03	1.421	0.062	1.275–1.599	140

Sampling plan

The sequential sampling plan (for $D = 0.3$) is presented in Figure 2. To use the plan, a crop scout 'tracks' the cumulative number of eggs (T_n) and the cumulative number of plants sampled (n) on the graph. Sampling ceases when the critical stop-line is intersected. The population density, as mean number of eggs per sample unit, can then be calculated, and compared to the action threshold to make a spray decision.

Figure 2. Sequential sampling chart for *Helicoverpa* on fresh-market tomatoes. D = 0.3



The mean number of samples taken over the 1000 re-sampling iterations decreased rapidly with increasing population densities (Figure 3). There were a few occasions where the re-sampling program had to take a very large number of samples ('spikes' in n_{max} in Figure 3). Each of these was from a data set where there were very few plants infested, and the numbers of eggs on these plants were high.

Figure 3. The mean (dots), minimum (dashed line), and maximum (solid line) sample sizes 'collected' over 1 000 re-sampling iterations. The heavy solid line represents the theoretically calculated minimum sample size

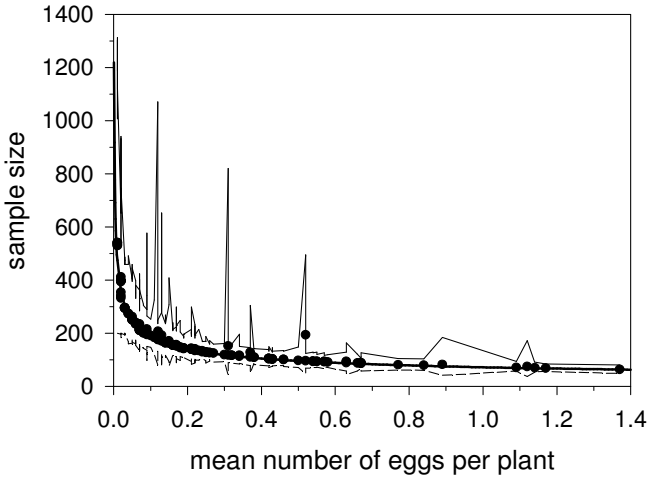
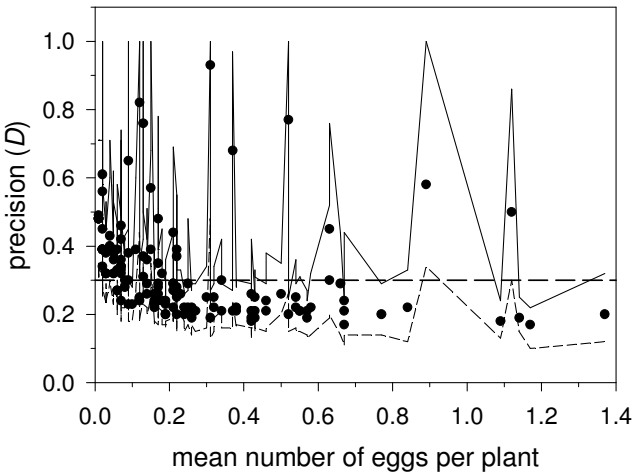


Figure 4. The mean (dots), minimum (dashed line), and maximum (solid line) levels of precision (*D*) achieved over 1 000 re-sampling iterations. The heavy/long dashed line denotes the nominal level of precision (*D* = 0.3).



The level of precision achieved by the plan tended to be less (i.e. greater *D* value) than the desired level of precision (*D* = 0.3) for low population densities, but higher than specified for medium and high densities (Figure 4). The plan generally performed well with respect to nominal level of precision, but there were data sets for which even 1,000 iterations was inadequate to achieve sufficient precision. These were typically data sets where there were very few plants infested and the numbers of eggs on these plants were high.

Discussion

The spatial distribution of *Helicoverpa* in fresh market tomato crops was found to be aggregated. Aggregated spatial distributions have been observed for *Helicoverpa* on cotton (Zalucki *et al.* 1986, Hassan *et al.* 1979) and soybeans (Terry *et al.* 1989).

The spatial distribution could be affected by a number of factors including host plants, cultural practices, and the presence or absence of predators. Calendar spraying at 7 to 10 day intervals occurs in the fresh-market tomato industry, and it may be that a lack of suitable places to lay eggs after spraying may cause moths to lay large numbers of eggs in one place. Predators could also affect oviposition (Hassan *et al.* 1979). The presence of predators may affect plant selection, with moths ovipositing in areas where there are fewer predators (Bernays & Chapman 1994). Even in cotton crops, which are theoretically of uniform genetic quality, age and condition, *Helicoverpa* shows a clumped spatial distribution (Wilson & Room 1982, Hassan *et al*. 1979, Zalucki *et al.* 1986). Nutritional effects from the larval host plant, the height of the host plant, and the health and vigour of the plant, can vary within crops. The response of individual females to various cues such as plant quality and morphology may also vary (Zalucki *et al*. 1986).

To produce a sampling plan that is practical for growers a precision of *D* = 0.3 was used. While at low population densities the precision being achieved was lower than

0.3, higher levels of precision are being achieved where needed, when there are intermediate to high densities.

In summer, the period of our data collection, the hot weather means that the lifecycle of the *Helicoverpa* is shorter, therefore larvae develop more rapidly and move into fruit quicker than in cooler weather. A shorter lifecycle and high oviposition means that calendar spraying can miss egg hatchings, with larvae quickly moving into areas where they are protected from insecticides. Regular sampling, twice weekly during summer, using a sampling plan should, pick up intermediate to high oviposition.

Considering the size and dimension of typical fresh market tomato crops in Australia, we suggest that growers choose rows haphazardly (or at random if they wish to go to the effort) and sample plants at 20 m intervals within rows. Continue sampling until the end of the row is reached, or the sequential stop rule is satisfied, and then continue along the next chosen row. If the rows are long, then the end at which sampling starts could be alternated each time. Alternatively, the starting end could be chosen at random each time by tossing a coin. Even though they may save some time, we do not recommend cluster sampling protocols, whereby plants (sampling units) would be sampled in distinct groups (clusters) before moving on to the next cluster. The sampling plan itself would need to be adjusted if such a protocol was used (Hamilton & Hepworth 2004).

Clearly there is a trade-off between time-spent sampling and the accuracy of the resulting pest management decision. A practical sampling plan, like that presented in this paper, provides growers with a means of estimating the pest density whilst not being too time-consuming.

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Section 6 Resistance Management

Resistance Management Strategy for *Helicoverpa* in Fresh Market Tomatoes

Introduction

The main reason resistance has developed is because of the repeated and often uninterrupted use of insecticides with the same mode of action. Selection of resistant strains can occur in as little as 3-4 years if no attention is paid to resistance management. The continued use of products with the same mode of action over successive pest generations has imposed high selection pressure on pests resulting in resistance. *Helicoverpa* has several generations in a cropping season. To help prevent insecticide resistance it is important that insecticides from the same chemical mode of action group are not used on successive generations during the season.

There are major disadvantages with conventional insecticides. One is the ability of the pests to develop resistance. Another problem with insecticides is that they can kill beneficials, disrupting biological control by killing predators and parasites. The situation often allows secondary pests to rapidly increase in numbers since there are no predators to prevent population explosion. However insecticides still remain one of the main tools for controlling pest species so managing insecticides to avoid resistance is essential.

Resistance management strategies decrease the selection pressure on chemical groups by rotating chemicals from different mode of action groups. This provides an effective means of managing resistance. For newer chemistries in the fresh market tomato industry where resistance has yet to develop these strategies could prevent the development of resistance. For chemistries where resistance has already developed there are two possibilities; (1) If there are fitness disadvantages to developing that resistance then there will be a decline in resistance in the absence of selection pressure (Roush & McKenzie, 1987), (2) If there is no fitness disadvantage then the resistance management strategy will simply delay further resistance and there will be no decline in resistance (Roush & McKenzie, 1987).

This resistance management strategy discusses the chemical groups and their mode of action, spray application, explanation of resistance, migration, *Helicoverpa* life cycle & vulnerable life stages and a strategy for insecticide use to control resistance developing.

Mode of Action Groups

Explanation of chemical groups

Group	Chemical Type	Active Constituents	Mode of Action
1A	Carbamate	Methomyl, Thiodicarb.	Acetyl Cholinesterase inhibitor (The presence of cholinesterase inhibiting chemicals prevents the breakdown of acetylcholine).
1B	Organophosphate	Dimethoate, Methamidophos	Acetyl Cholinesterase inhibitor
2A	Cyclodienes	Endosulfan	Chlorinated Hydrocarbon insecticide
3A	Pyrethroid	Cypermethrin, Beta-cyfluthrin, Esfenvalerate, Deltamethrin, Bifenthrin	Sodium Channel Modulator. Affects the function of the nervous system by interfering with the operation of sodium channels in the nerve membrane.
5A	Spinosyn	Spinosad	Spinosad kills susceptible species by causing rapid excitation of the insect nervous system (leading to involuntary muscle contractions, prostration with tremors and paralysis)
6A	Avermectins, Milbemycins	Emamectin benzoate	Chloride channel activators
11C	Bacillus thuringiensis	Bacillus thuringiensis	A toxin which causes the larva to stop feeding
16A		Methoxyfenozide	Ecdysone Agonist. Causes premature lethal moult in many species of lepidopteran larvae. The larvae are unable to complete the moult and die within the old skin that cannot be shed.
22A	Indoxacarb	Indoxacarb	Voltage dependent sodium channel blocker – Kills by binding to a site on the sodium channel and blocking the flow of sodium ions. The result is impaired nerve function, feeding cessation, paralysis and death.

Spray Applications

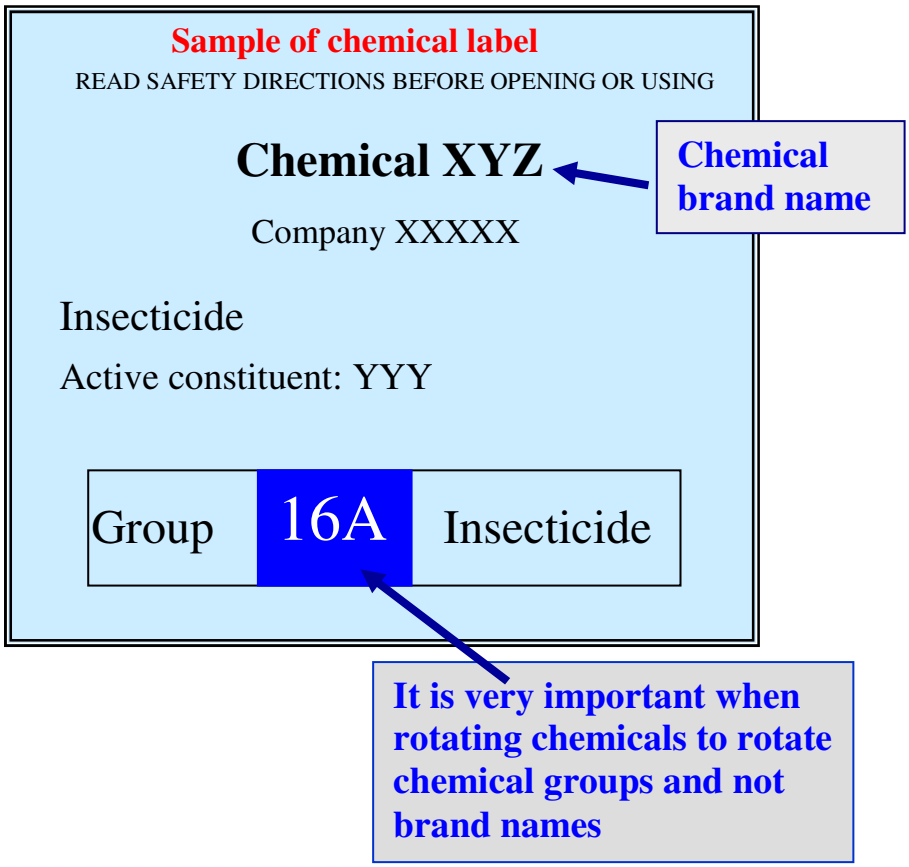
Label recommendations should be followed for rotating or mixing products, and for insecticide rates and spray intervals. Rates should not be increased or decreased from the manufacturer recommendations, unless an IPM rate is included on the label. Insecticide labels give label rates that provide the most effective control of the pest. Full recommended rates of registered insecticides should always be used to ensure the most effective control of the pest. The majority of insecticides require good coverage of the target area to ensure the best possible chance of contact and subsequent control of the pest. Sprayer nozzles should be checked for blockage and wear, and be able to handle pressure adequate for good coverage and they should be checked and calibrated on a regular basis.

Rotate insecticides using different modes of action (different chemical groups) not different brands. A chemical group should not be sprayed over successive generations of *Helicoverpa*.

Tank mixes may select for individuals with resistance to more than one insecticide. Tank mixes should only be used in situations where multiple pests are present or where the pesticides of choice kills only certain stages of the pest.

Frequent spraying of insecticides, and spraying over successive generations can all increase resistance.

Example of a chemical label – Rotate Chemical Groups (ie/ 16A)



Broad spectrum insecticides are not specific to a particular species and their use has resulted in very low levels of biological controls (beneficials) in crops.

Selective insecticides target a specific pest species and are generally less harmful to biological controls than broad-spectrum sprays.

Insecticide resistance

An insect is resistant to an insecticide if once exposed it can still survive and breed. Each application of the insecticide favours the survival of the resistant individuals over the susceptible individuals. If the mode of action group is used too frequently, the numbers of pests that inherit the insecticide resistance will become proportionately greater in each generation, until the pest population consists mostly of individuals that are resistant to the insecticide.

With the costs of developing new insecticides replacement chemicals come on the market infrequently so we need to ensure that the insecticides that are registered now stay effective for as long as possible.

What is cross-resistance?
If an insect develops resistance to one pesticide, it may also be resistant to other closely related pesticide, even if the population has not yet been exposed to that second pesticide. This is cross-resistance. For example, insects that become resistant to one pyrethroid tend to be resistant to all pyrethroids.

What is multiple resistance?
Multiple resistance is when a pest has more than one mechanism of resistance to an insecticide or has resistance to more than one mode of action group.

What are the mechanisms of resistance?
There are four basic mechanisms of pesticide resistance in arthropods:

Metabolic resistance is where the insect uses various enzymes to detoxify (destroy) the pesticide before the poison can kill the insect. These enzymes are already in the insect, and resistant insects produce more of the enzymes, detoxifying or destroying the toxin faster than susceptible insects. Metabolic resistance is the most common form of resistance.

Target site resistance is another mechanism of resistance that occurs when the insect changes the structure of an enzyme or the function of part of its nervous system to reduce the effectiveness of a pesticide that acts on that site. The target site has been genetically modified to reduce the pesticide effects. Target site resistance is the second most common form of resistance.

Resistant insects may absorb the toxin slower than susceptible insects –reduced penetration of the pesticide. Penetration resistance is usually present along with other forms of resistance, and reduced penetration intensifies the effects of those other mechanisms.

Behavioural resistance, the other mechanism of pesticide resistance, consists of changes in the habits or actions of the insect to avoid exposure to a pesticide, ie moving to a part of the plant that has not been sprayed, underneath leaves, inside fruit.

Reduced penetration of insecticides and behavioural changes are not linked to any site of action classification but are specific for individual compounds or chemical groupings. Despite this, rotation of chemical groups is still the best way to manage resistance as it reduces selection pressure.

How does resistance develop?

Some insects will naturally have resistance to a particular insecticide. Spraying this insecticide will mean these naturally resistant individuals survive and breed, while susceptible individuals are killed. Continued used of the same insecticide will eventually mean that a large portion of the population is resistant and the insecticides are no longer effective leading to field failure of insecticides.

Implications of spraying the same chemical over different generations

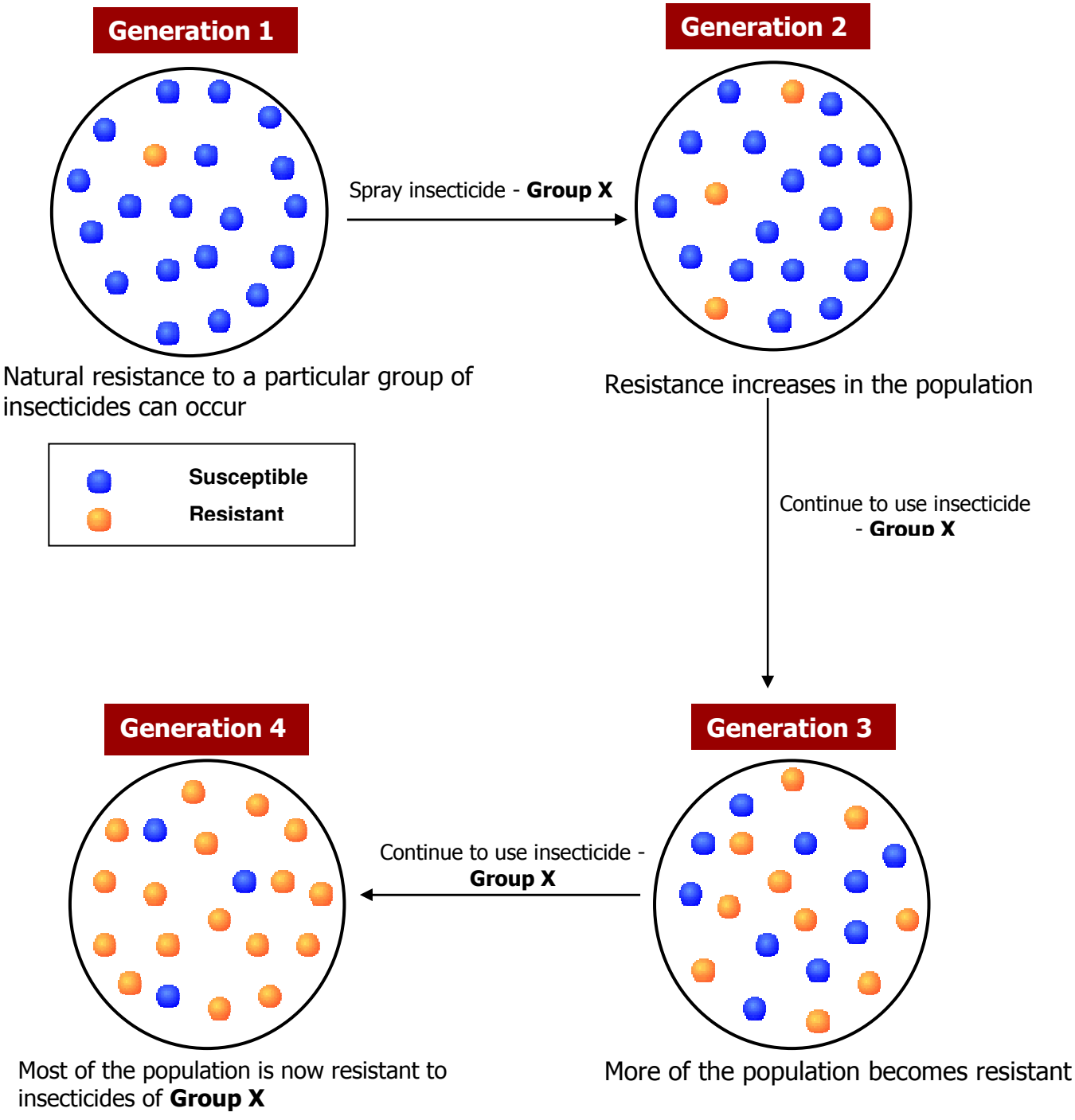
Figure 3:

Generation 1 Some individuals have genetic traits that allow them to survive a pesticide application.

Generation 2 A proportion of the survivors' offspring inherits the resistance traits. At the next spraying, these individuals will survive.

Generation 3 & 4 If pesticides are applied frequently, the pest population will soon consist mostly of resistant individuals.

An example of how resistance develops when the same chemical group is used over several generations



Insects that have a resistance to a particular group of insecticides (mode of action) may be vulnerable to another group of insecticides. Rotating chemical groups could avoid the above scenario.

If a large portion of the population is regularly sprayed with the same insecticide, resistance will develop quickly

Managing Resistance

A resistance management strategy reduces the number of applications of any one mode of action group in order to delay development of resistance to insecticides. The strategy includes rotating different mode of action groups, using selective insecticides so that natural enemies will survive and help control the pest population, and using cultural techniques such as pupae busting to reduce the pest population.

Key steps to slow the development of resistance – an integrated approach:

- Monitor pest populations for timing and application decisions. This is an essential step in a resistance management program. A good understanding of the lifecycle of the pest is needed, as insecticides need to be applied to the vulnerable life stages of the pest.
- Maintain good plant health.
- Limit selection pressure all season long by:
  - Limiting your use of each mode of action group.
  - Rotate modes of action from one generation to the next.
  - Use the rates on the label of insecticides and avoid repeat applications of the same mode of action insecticide.
  - Use the most selective insecticides first so natural enemy populations can build and help out (selective insecticides target a specific pest)
  - Limit broad-spectrum insecticide applications.
  - Tank mixes of insecticides should be avoided unless there are multiple pests being targeted
- Use all available tactics to manage the target insect, including chemical, cultural, and biological means
- Incorporating cultural and biological controls will reduce the selection pressure on insecticides.
  - Destruction of over-wintering (diapause) pupae by cultivation – pupae busting.
  - Removal and destruction of crop residues after harvest. This will eliminate food sources and over-wintering habitats for pests and reduce potential sources of disease for the next crop.
  - Using trap crops to reduce the overall abundance of a pest

Refuge crops to maintain beneficial populations. Beneficials will eat or parasitise resistant as well as susceptible pests. Refuge crops can also preserve susceptible genes by providing a haven for susceptible insects. Susceptible insects can then interbreed with resistance ones and hence dilute the resistant population.

Remember that when you spray for one pest you may affect other pests, and as such you may affect resistance levels in other pests.

Report on resistance testing of *Helicoverpa armigera* and *Helicoverpa punctigera*

Results

The most commonly used chemicals have been tested for resistance. Resistance testing was conducted on both *Helicoverpa armigera* and *Helicoverpa punctigera.*

Results from IPM project

Results from resistance testing showed that there was resistance developing in *Helicoverpa* in northern Victorian fresh market tomatoes, to some commonly used chemicals (carbamates and pyrethroids). Results of laboratory testing show that the pyrethroid resistance factor (RF) is 32. This means the RF is relatively high in the Goulburn Valley, RF 15 or less is acceptable. Some carbamate resistance was present so only 40% were killed compared to a susceptible strain. The level of resistance suggests that even small larvae would not be killed by field rates of carbamates. 100% of the population was resistant to pyrethroids and 40% of the population was resistant to carbamates.

Results from ICM project

H. punctigera

Sample number	Date Collected	Methomyl Carbamates	Fenvalerate Pyrethroids	Spinosads	Endosulfan
1	17th Nov	25%	0	0	0
2	29th Nov	38%	7%	0	12%
3	9th Dec	20%	0	0	0
4	30th Dec	12%	0	0	0
5	24th Jan	15%	0	0	0
6	31st Jan	11%	0	0	0

H. armigera

Sample number	Date Collected	Methomyl Carbamates	Fenvalerate Pyrethroids	Spinosads	Organophosphates
1	9th Feb	63%	94%	19%	13%
2	18th Feb	57%	100%	0%	12%
3	21st Feb	60%	97%	11%	0%
4	23rd Feb Organic	42%	92%	0	0
5	3rd Mar	50%	100%	19%	0
6	16th Mar	54%	100%	15%	0

Results show increasing resistance for *Helicoverpa armigera* to carbamates and spinosads, with resistance to pyrethroids between 92% and 100%. *H. punctigera* showed some resistance to carbamates, although this is a lot smaller than the carbamate resistance in *H. armigera*. *H. punctigera* also showed a very small amount of resistance to pyrethroids and endosulfan for one sample. Resistance to spinosads and organophosphate is a worrying trend. An industry resistance

management strategy could slow down further resistance to these groups. Resistance to spinosads was persistent throughout the season.

Primarily insecticide applications were targeted to control the main pest *Helicoverpa*. There is limited grower use of new chemicals, such as methoxyfenozide, emamectin and indoxacarb. These new chemicals are targeted for specific pests and are known to be less harmful to beneficials.

There are a number of examples where repetitive applications of the same chemical group occurred over the different generations of *Helicoverpa*. Often chemical programs included the application of two or more insecticides at the same time and these insecticides were likely to have been combined in the spray vat. The number and frequency of insecticide applications was quite variable between growers and between seasons.

Very low populations of *Helicoverpa* in some years due to unfavourable conditions have seen little reduction in the number of sprays applied for the control of *Helicoverpa*. Chemical spray programs spray regardless of pest abundance and the likelihood of unnecessary sprays being applied under these conditions is very high.

Migration of Helicoverpa

How migration can influence resistance?

Helicoverpa moths have a 1-3 day pre-reproductive period after emergence from the pupae, during this period they may migrate. Moths are capable of flying long distances (long distance migration) as well as moving extensively among fields within a region (local migration).

H. punctigera frequently reproduce during the winter season on flowering plants within inland regions of Australia. *H. punctigera* are obligate migrants, and migrate without regard to environmental cues (Fitt et al 1995, Rochester, 1999). With the onset of spring, these moths migrate to cropping areas. The number of moths participating in this migration is largely determined by rainfall and the abundance of host vegetation during the winter period. In contrast, *H. armigera* tends to over-winter as pupae in the soil of late planted summer crops and therefore remains in the local area. *H. armigera* are facultative migrants and only migrate when local conditions are poor or when weather conditions are favourable (Fitt 1989, Rochester, 1999). Moth emergence from these over-wintering pupae often begins between September and October. Small numbers of *H. armigera* emerge in spring and often take several generations to build up to high numbers. Crop damage by *H. armigera* is therefore most common during the later part of the summer season.

Resistance has become an increasing problem on fresh market tomatoes in the Goulburn Valley. Resistance can vary from region to region. It is important to know if the moth populations are local populations or immigrant populations. If the moth populations are local then resistance to chemical controls is likely to be the result of local management practices. If the moths are largely immigrants then resistant moths could be moving in from other regions. This will have implications for the way resistance is managed in this region.

Migration in the Goulburn Valley region

In the Goulburn Valley region microsatellite analysis showed that 20 to 30% of *H. armigera* moths migrated from other cropping regions. Most of these moths came from the Murrumbidgee Valley with a smaller amount coming from the Darling Downs and MacIntyre Valley. This has implications for the industry because resistant moths could be migrating into the region and therefore increasing the likelihood of resistance leading to field failure levels.

Local migration (short distance migration) will also impact on resistance management. With 70 to 80% of the *H. armigera* population local, it is local migration that will impact most on resistance management for the industry. The impact of spray programs of one grower will affect others in the region.

When is migration likely to occur?

Microsatellite analysis shows that the occurrence of long distance migration will vary from year to year. Both short and long distance migration will occur throughout the year.

Helicoverpa **life cycle**

Helicoverpa grow rapidly, especially over the summer, and a delay in applying a chemical can result in high fruit damage and control of large larvae is difficult. Crops need to be monitored and chemical sprays applied based on pest abundance. Applications of insecticides should be made against the most vulnerable life stage of *Helicoverpa*. The most vulnerable life-stages of *Helicoverpa* are the egg stage and the 1st and 2nd instar larvae. After the 2nd instar, larvae become increasingly difficult to kill due to higher resistance to chemicals and because they will move inside fruit where they are protected from chemical applications.

Egg stages - white (freshly laid), brown, opaque with black head (about to hatch), black (parasitised). Eggs can hatch in 3 days over summer (up to 7 days in cooler periods). The complete lifecycle can be as little as 4 weeks over summer and up to 16 weeks in cooler weather.

Development times for *Helicoverpa*

	18°C	**25°C**	**28°C**
Eggs	5	3	2
Larvae	32	20	15
Pupae	32	16	12
Total	**69**	**39**	**29**

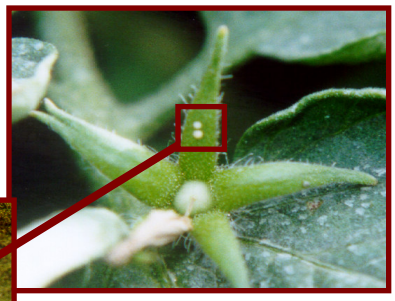
Temperatures above 35°c can reduce fertility and fecundity of moths, temperature increases above 38°c reduces egg survival, (Rochester 1999).

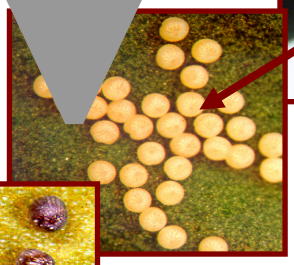
Helicoverpa (Tomato Grub) life cycle

Helicoverpa Moth

Pupae - When a caterpillar is fully grown, 4-5cm, it pupates in the soil. *Helicoverpa* overwinter as pupae in the ground at depths between 2-18cm. The overwintering phase can last 5 months

Vulnerable life stage





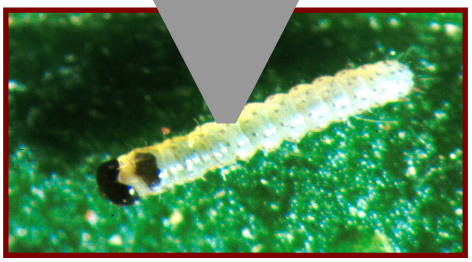
Helicoverpa Eggs are layed on leaves, flowers, flower buds and developing fruit.

During hot weather eggs will hatch within 3-5 days, it may take 6-16 days in cooler weather.

Stages of *Helicoverpa* egg development:
White eggs - freshly laid
Brown eggs - slightly developed
Black spot - about to hatch

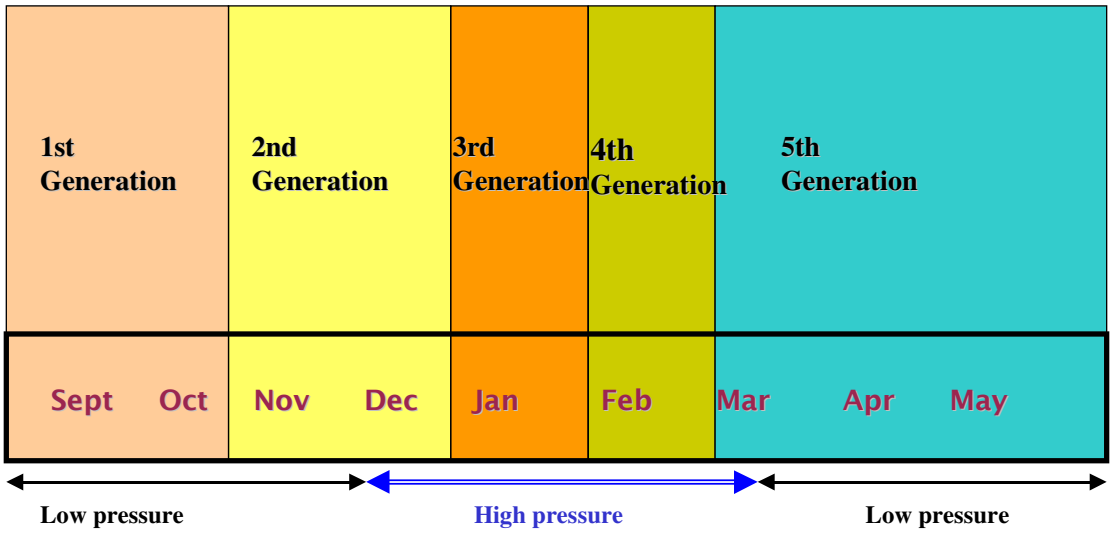
5th/6th Instar caterpillar - Caterpillars have six instar stages after which the caterpillar reaches a maximum length of 4-5cm. This can take 2 weeks in hot weather and 5 weeks in cooler weather. *H.punctigera* is the dominant species in spring and early summer. *H.armigera* is more common from mid-summer onwards.

Vulnerable life stage



Newly hatched *Helicoverpa* - first instar

Helicoverpa generations



Other pests

1. Western flower thrip

Western flower thrips (WFT) was first identified in Goulburn Valley in Spring 2002 and is a potentially devastating pest of tomatoes mainly as an efficient vector of Tomato Spotted Wilt Virus (TSWV). Tomato Spotted Wilt Virus has caused significant damage to tomato and vegetable crops in Australia in the last few years, for example an estimated $90,000,000 lost in the Adelaide Hills in a single season. The main problem with controlling western flower thrips is the high level of resistance it has developed to many of the chemicals available for controlling thrips.

Western Flower Thrips resistance testing:

WFT were obtained from a flower nursery in Murchison for resistance testing by Grant Herron's team in NSW Agriculture. No WFT were found in fresh market tomatoes in the 2003-2004 season.

	Resistance Factor - RF	Confidence Interval - CI	Percentage mortality at the discriminating dose - % Mortality
Abamectin	~1.0	N/A	100
Acephate	~1.0	N/A	100
Chlorpyrifos	4.5	2.6-7.7	52
Dichlorvos	1.5	1.1-2.2	94
Endosulfan	~1.0	N/A	100
Fipronil	~1.0	N/A	100
Malathion	3.0	2.0-4.6	98
Methamidophos	~1.0	N/A	100
Methomyl	1.4	1.0-2.0	94.5
Spinosad	~1.0	N/A	100

The WFT samples sent to NSW were tested against 10 chemicals.

WFT were found to be:

- **Susceptible** to abamectin (6A), acephate (1B), endosulfan (2A), fipronil (2C), methamidophos (1B) and spinosad (5A)
- **Slightly resistant** to dichlorvos (1B), malathion (1B) and methomyl (1A)
- **Very resistant** to chlorpyrifos (1B).

WFT are also know to be highly resistant to pyrethroids.

Importantly all chemicals which work on western flower thrips, will also affect *Helicoverpa* and because of this they can affect resistance levels in *Helicoverpa*. It is important to get western flower thrips positively identified, which needs to be done under a microscope, before applying sprays for this pest. Remember other thrips species can pass on the tomato spotted wilt virus so seeing this disease in your crop does not necessarily mean that western flower thrips are present.

So far western flower thrips have not established in fresh market tomato crops in the Goulburn Valley.

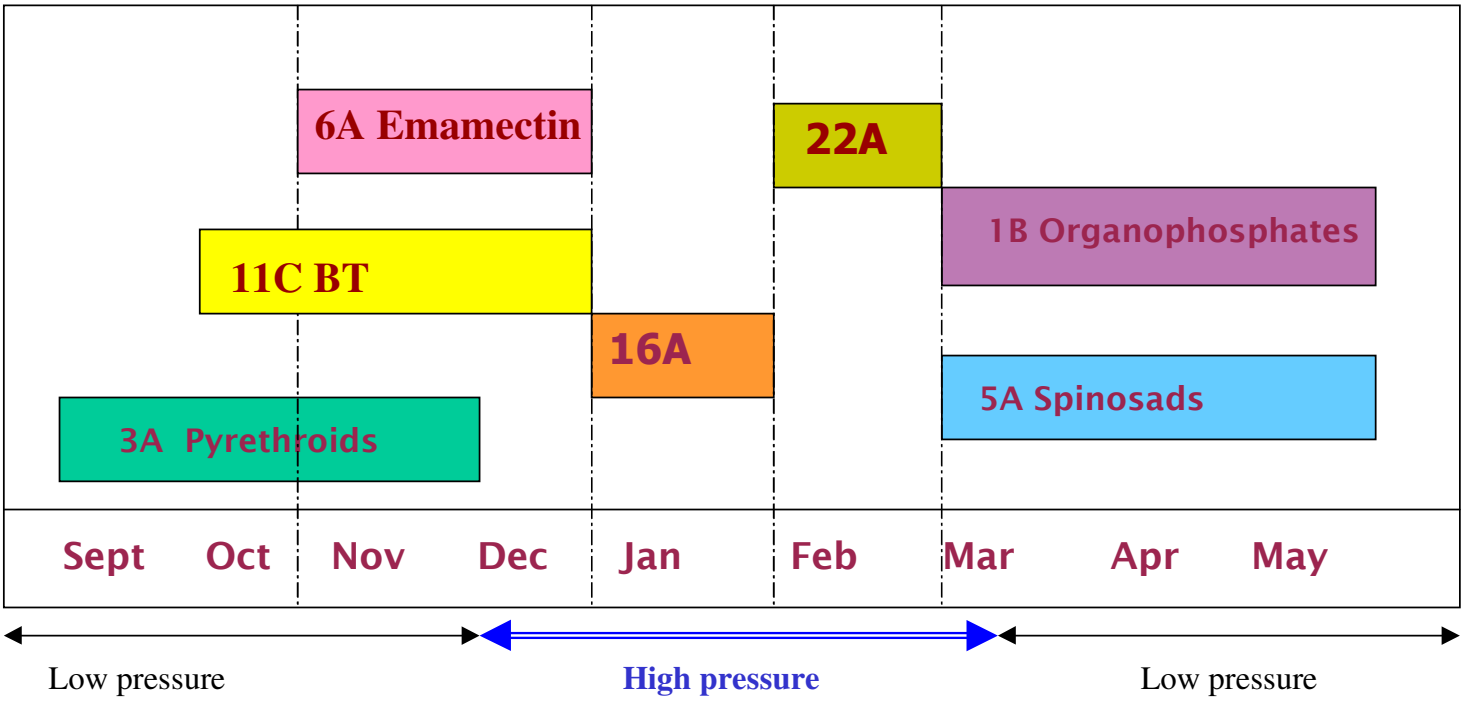
2. Others

Flares of aphid and mites are caused through the use of broad-spectrum sprays killing all the biological controls (beneficials) which if present could keep the aphid and mite numbers down to manageable levels and below economic damage.

Area wide resistance strategy

Short and long distance migration means that a resistance management strategy must be implemented on an industry wide basis.

Overall strategy



1B	Organophosphates	eg	Nitofol ®, Orthene ®, Lorsban ®
3A	Pyrethroids	eg	Fastac ®, Bulldock ®, Talstar ®, Hallmark ®, Ballistic ®, Sumi-Alpha ®
5A	Spinosyn	eg	Success ®
6A	Emamectin	eg	Proclaim ®
11 C	Bacillus thuringiensis	eg	Dipel ® DF
16A	Methoxyfenoxide	eg	Prodigy ®
22A	Indoxacarb	eg	Avatar ®

- Carbamates have been left out of the strategy for this year due to a very high level of resistance in *H. armigera* and low to moderate resistance levels in *H. punctigera*.

- Pyrethroids have been restricted to spring so they are used only *on H. punctigera*, which are still susceptible to this insecticide.

- The use of BT and 6A chemicals early in the season is preferred as this will help preserve beneficial populations which will decrease the likelihood of flares in secondary pests.

- Spinosads are restricted to the end of the season because orchards use them in spring and there needs to be some generations which are not sprayed with spinosads

Monitoring

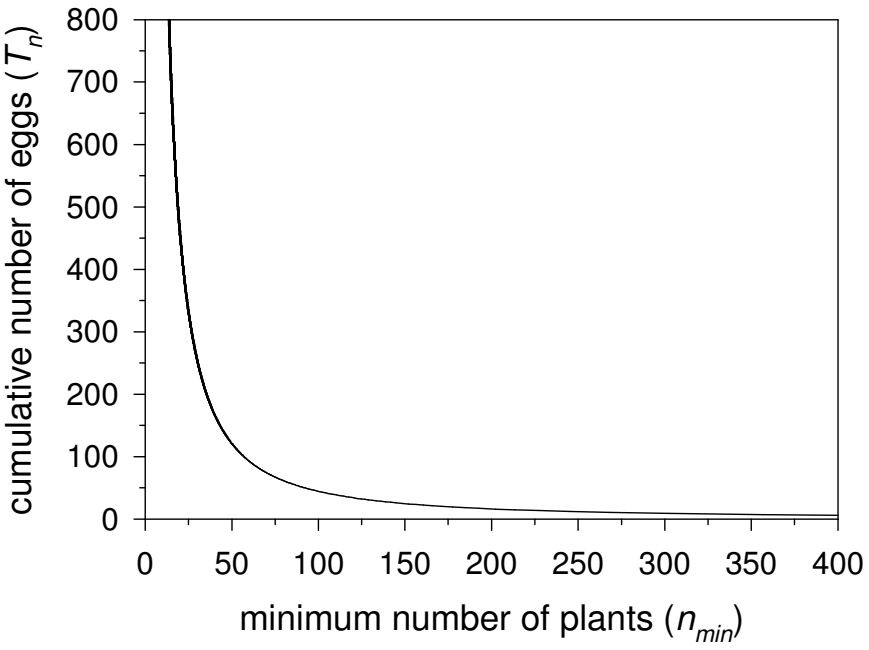
Thresholds and a Sampling plan

In many crops the decision to spray is based on action thresholds. Effective use of thresholds is dependent upon accurate sampling to provide reliable estimates of pest density. The action threshold for *Helicoverpa* eggs used in the processing tomato industry is 5 eggs per 30 leaves. As no action threshold has been developed for the fresh market tomato industry, the threshold for the processing tomato industry can be used as a guide. An action threshold of 5 eggs per 30 leaves is 0.5 eggs per sampling unit (the sampling unit in fresh market tomatoes is the first three fully expanded compound leaves) in fresh market tomatoes. At an action threshold of 0.5 eggs per sampling unit the sampling plan requires around 100 samples to be collected.

It is important to monitor eggs regularly. To do this requires a monitoring system that is practical: a system that is easily implemented and is not time-consuming for growers. Sequential sampling plans are less time-consuming than other monitoring methods, particularly if pest populations are well above or below the threshold.

Considering the size and dimension of typical fresh market tomato crops in Australia, growers should choose rows haphazardly (or at random if they wish to go to the effort) and sample plants at 20 m intervals within rows. Continue sampling until the end of the row is reached, or the sequential stop rule is satisfied, and then continue along the next chosen row. If the rows are long, then the end at which sampling starts could be alternated each time. Alternatively, the starting end could be chosen at random each time by tossing a coin. Even though they may save some time, we do not recommend cluster sampling protocols, whereby plants (sampling units) would be sampled in distinct groups (clusters) before moving on to the next cluster. The sampling plan itself would need to be adjusted if such a protocol was used.

Clearly there is a trade-off between time-spent sampling and the accuracy of the resulting pest management decision. A practical sampling plan provides growers with a means of estimating the pest density while not being too time-consuming.



Thresholds should only be used as a guide. Other things such as the level of parasitism, the number of general predators, weather conditions, the ability to respond rapidly to pest pressure and the stage of the crop should be taken into account before sprays are applied.

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Fitt, G. P. (1989). The Ecology of *Heliothis* species in relation to agroecosystems. *Annual Review of Entomology*. **34**: 17-52

Fitt, G. P, Dillon, M. L, Hamilton, J. G. (1995) Spatial dynamics of *Helicoverpa* populations in Australia: simulation modelling and empirical studies of adult movement. *Computers and Electronics in Agriculture*. **13**: 177-192

Rochester, W. A (1999). The migration systems of *Helicoverpa punctigera* (Wallengren) and *Heliocoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in Australia. PhD thesis. University of Queensland. Queensland, Australia. 120pp

Roush, R. T and Miller, G. L. (1987). Ecological genetics of insecticide and acaricide resistance. Annual Review of Entomology. **32**: 361-380

Other sources of information on resistance

Websites:

Avcare Australia - http://www.avcare.org.au/

Australian pesticide and Veterinary Authority - http://www.apvma.gov.au/users/subpage_users.shtml

Insecticide Resistance Action Committee – http://www.irac-online.org/

Michigan state university - http://whalonlab.msu.edu/rpmnews/

Nutrient Management

General Introduction

The consistent production of a high quality fruit crop requires careful nutrient management. There are 16 essential nutrients required for plant growth, and these can be divided into those that are needed in large (macro) or small (micro) amounts. The macro-nutrients comprise carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). The micro nutrients, also known as trace elements, are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl). Of these, all except carbon, hydrogen and oxygen are derived from the soil. When the soil cannot supply the level of nutrient required for adequate growth, supplementary fertiliser applications become necessary (Rosen and Eliason, 2002).

Fertigation is the application of water-soluble fertilisers through the irrigation system, and allows the controlled placement of nutrients near the plant roots. This technique can reduce fertiliser losses through leaching and provides more flexibility in a fertiliser program. Drip irrigation adds further potential for the accurate and timely delivery of both water and nutrients throughout a field. Studies have shown that under drip, uniformity of applied water and chemicals is higher across the field than with other irrigation methods (Gardenas *et al.* 2004). Alsinan (1998) and Schwankl and Prichard (2001) reported that the uniformity of chemical applications is partly controlled by the injection period, which needs to be calculated with consideration of the travel time for applied water to move through to the end of the line. A drip irrigation system should be designed and operated so that water and nutrients are applied at a rate, duration and frequency that maximises crop water and nutrient uptake, while minimising leaching of nutrients and chemicals from the root zone.

Trellis tomato producers in northern Victoria use drip irrigation exclusively, including for the distribution of fertilisers to the crop. Although most can be injected successfully into drip irrigation systems, the nutrients most commonly applied in this manner are nitrogen (N) and potassium (K), both of which are mobile and are required in relatively large quantities during the season (Hartz and Hochmuth 1996). Uniform application of nutrients to the root-zone through fertigation increases the efficiency of application as well as saving money, and reduces leaching and denitrification. It can also save energy and labour, provides flexibility and convenience, and importantly, supply can be regulated and monitored (Imas 1999).

Because of the complex nature of nutrients (particularly nitrogen) in the soil, it is difficult to know how much fertiliser to apply. Under or over fertilisation can often occur, and the use of soil and plant tissue testing can be a valuable tool for determining fertiliser needs and maximising application efficiency.

Victoria is Australia's major tomato-producing state and is the primary source of tomatoes destined for Australia's fresh markets during summer and early autumn. The fresh tomato industry of the region produces more than 48,000 tonnes annually (ABS Census, 2001). In recent years, the fresh market industry has moved significantly to production of indeterminate tomato varieties, which require trellising and more intensive management than was the case for ground crops. Such varieties are sensitive to nutrient application, and farmers are currently trying many strategies in order to maximise their yields. The lack of information on this subject can lead to inefficient practices, which may impact on crop yield and quality, with potential risks of leakage to the surrounding environment. This project was designed to provide trellis tomato growers in northern Victoria with guidelines and monitoring tools to maximise the effectiveness of their fertiliser applications. Preliminary information

was also collected from ground crops, both for comparative purposes and to initiate the development of similar guidelines for these crops.

Section 1 – Fertigation Benchmarks

Introduction

Benchmarking involves comparison of prevailing practices to identify those that produce the best results in terms of productivity and efficiency. The approach has been widely used in agriculture, and allows farmers to compare their performance in a particular aspect of management with that of others, and to identify areas for improvement. Peer support networks often develop from benchmarking activities, enhancing the adoption of best practices.

Fertigation refers to the application of water-soluble fertiliser to crops through irrigation water. Nutrients in a concentrated solution are injected into the water that is delivered to plants via irrigation. Drip irrigation is considered ideal for fertigation, as it supplies water directly to the plant's root zone. When properly managed, a drip irrigation system distributes water uniformly across a paddock, and can be used to accurately regulate crop feeding. The precise and uniform application of nutrients to the root-zone through fertigation increases the efficiency of application, saving money in fertiliser, energy and labour costs as well as reducing nutrient losses to the environment. Such a system is flexible with respect to timing and quantity delivered, and can be effectively regulated and monitored (Imas 1999).

Trellis tomato producers in northern Victoria use drip irrigation exclusively, including for the distribution of fertiliser to their crops. Production of indeterminate tomato varieties on trellis is relatively new to the area, and fertiliser application strategies still vary significantly between growers, who lack definitive local guidelines for the nutrition of their crops.

While both the macro and micronutrients were measured in this study, particular focus was placed on nitrogen and potassium, which are required by the crop in large amounts.

Nitrogen has the greatest effect of all nutrients on plant growth and uptake of other nutrients, and so is the most important nutrient to control (Ingestad 1977). This has been widely demonstrated in tomatoes where yield and vegetative growth increase with rates of applied nitrogen (for example Bar-Yosef and Sagiv 1982; Huett 1986). It is important not to add excessive nitrogen, as this not only adds cost to the farmer but can create environmental problems through leaching (Pier and Doerge 1995; Thompson and Doerge 1995). Nitrogen fertilisers are soluble and well suited to fertigation. Regularly applied small doses of nitrogen have also been found to produce higher yield than the traditional small number of large ones (Singandhupe, 2002). Recommendations for nitrogen application have also been based on phenological stages (eg. Fullelove *et al.* 1998).

Although local soils are generally rich in potassium, crop demand for this element is high because it is essential constituent of a variety of metabolic processes in plants (Glendinning 1990). Potassium fertilisers are relatively soluble, and are therefore well suited to application through a fertigation system. Almost all phosphorus is applied to crops as a base dressing prior to planting, as it is relatively insoluble and can cause clogging problems if applied through the drip system (Hebbar *et al.* 2003, Rosen and Eliason 2002). Some trace nutrients such as copper, iron, manganese and zinc may also precipitate in high pH water.

Regular soil testing (once a year) can help to ensure that the correct amount of fertiliser is applied to the soil to satisfy the nutrient requirements of the crop. This requirement depends on the history of the paddock, and in the case of nitrogen for

example, could be quite low 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). For example, a tomato crop producing 194 t/ha has been estimated to remove a total of 572 kg N/ha (fruit: 361 t/ha, leaves and stems: 211 kg/ha), whereas a 45 t/ha crop has been estimated to remove 220 kg N/ha (fruit: 128 kg/ha, leaves and stem 92 kg/ha) (Glendinning 1990). Tomatoes are efficient at extracting residual soil nitrogen and the mineralisation component is an important source of nitrogen for tomato crops. It has been estimated that only 30-40% of the total nitrogen in a tomato plant with an effective rooting depth of 76 cm is derived from applied fertilisers (Hills et al 1983).

Plant analysis is a good tool for monitoring nutrient status, and for timely and efficient fertiliser applications it is helpful to analyse the nutrient levels in plant samples weekly in order to adjust the fertigation schedule for a particular crop. The total nitrogen content of leaves has been used for many years as a guide to predict crop requirements for N. Some reports suggest that high yielding plants should have from 3.0 to 4.0 % N in dried, most recently matured leaves at the mid-bloom stage of growth (Lorenz and Tyler 1983; Mills and Jones 1996). As well as an indicator of plant nutrient status, tissue nutrient levels can be used in benchmarking, to establish optimum crop nutrient requirements and guide application practices (Fullelove *et al.* 1998). The effectiveness of this approach depends on the ability of the grower to regulate nutrient applications in the field, and fertigation through a drip irrigation system is ideally suited to this purpose.

Published data on tomato sap nutrient levels includes figures for semi-determinate 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). Differences between these crops, their management systems and growing environments, lead to variation in the sap nutrient levels and consequent recommendations for crop nutrition, highlighting the benefits of developing this information to suit local conditions.

Methods

Experimental sites: Within this project, data were gathered from a total of 69 blocks over 3 growing seasons (2002/3-2004/5) in observation trials, incorporating the management practices of four trellis (53 blocks) and four ground (16 blocks, as only in the 2004/05 season) tomato growers. For some analyses, results from the first two seasons of this project (2002/3 and 2003/4) were combined with and built on those from a previous project (VX01027 – conducted in 2001/2), on the basis of consistency between methods and materials used for data collection. This approach also enabled each year's data to be treated as replicate for the purposes of statistical analysis. Each site was given a reference number to ensure the confidentiality of participating growers. Within each site, a 10m X 4.5m plot over three rows was randomly selected for collection of soil samples and petiole samples for sap analysis. Within this plot, a 2m length of the central row was used to estimate yield and fruit quality. All sites were planted with cv Red Ruby for trellis and Rebel for ground production. All sites were otherwise managed by the growers according to accepted commercial practices. The sites used in 2004/5 were set up as replicated experiments, to further test the relationships between nutrient levels and yield and fruit quality obtained from the three previous years. In replicated trials, plots were 10m long over three rows and were replicated four times within a randomised block design at each site. As in observation plots, yield and fruit quality from these trials

were also estimated from hand harvest of 2 metre representative sub-plots (generally in the centre, but chosen to avoid obvious gaps and diseased plats where necessary) within each plot.

Soil tests: Soil parameters were measured from the second planted block of each participating grower in 2003/4 and 2004/5 for trellis crops (8 sites in total). In ground crops, monitoring was only conducted in 2004/5 (4 sites). Samples (comprising 2 cores combined) were taken before planting and after harvesting, and from three depth intervals: 0 – 30 cm, 30 – 60 cm and 60 – 90 cm. Pre-planting samples were taken randomly from the cultivated field whereas post harvest cores were taken from midway between the bed centre and shoulder. Samples were analysed by the Serve-Ag chemistry laboratory at Devonport, Tasmania (2002/3, 2003/4) or by Farmright Technical Services at Kyabram, Victoria (2004/5). In the first year of the project (2002/3) only Nitrate levels were measured, whereas pH, Electrical Conductivity (EC), Total Nitrogen (N), Ammonium N (NH_4), Nitrate N (NO_3), Total Phosphorus (P) (Olsen and Colwell) and Potassium (K) (Skene) were measured in years 2 and 3.

Petiole sap analysis: Petioles were randomly collected from thirty plants (one petiole per plant) within each trial plot, but not from within the sub-plots used for yield and quality assessment. The petioles were taken from the most recently mature fully expanded leaves and were harvested prior to 11 am on each sampling day. After sampling, petioles were refrigerated prior to dispatch by express post to the analytical laboratory at Serve-Ag Pty Ltd in Devonport, or personally delivered to Farmright Technical services at Kyabram. Extruded sap from these petioles was analysed for Nitrate (NO_3), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and as micronutrient Zinc (Zn). In the 2003/04 and 2004/05 seasons, samples were also tested for other micro and macronutrients: Boron (B), Sulphur (S), Copper (Cu), Iron (Fe) and Manganese (Mn). Both trellis and ground crops were sampled at four growth stages as follows: Stage 1 =1^{st} - 2^{nd} flower, Stage 2 = 3^{rd} - 4^{th} flower, Stage 3 = 5^{th} – 6^{th} flower and Stage 4 = between 2^{nd} and 3^{rd} harvest. Six fruit were also selected at breaker maturity stage for measurement of firmness and soluble solids content in 2002/3 and 2003/4 trellis crops. These fruit were stored at 20^{o}C for 6 days before testing. Firmness was measured as compression (mm) resulting from the application of a 500g weight for 5 seconds (Sumeghy *et al*. 1983). Soluble solids content was measured with a portable refractometer using clear serum from the juice extracted from the bulked sampled tomatoes.

Yield and fruit quality analysis: Ripe fruit were harvested from the 2m sub-plots on a weekly basis, and graded into small (< 60 mm in diameter), medium (60 – 80 mm) and large (> 80 mm) sizes, which were subsequently weighed. In the final year (2004/5), unmarketable yield, comprising very small, misshapen, insect and sun damaged fruit, was also collected and weighed. These fruit were not differentiated with respect to the reason for unmarketability.

Data analysis and development of benchmarks: Results from soil analyses from 2003/4 and 2004/5 were averaged across years, with variability expressed as 95% confidence intervals. Similarly, plant data was combined across the three project seasons for analysis. The relationships between fertigation levels and yield or quality parameters at the monitored growth stages (% small, medium, large fruit and unmarketable fruit) were calculated using linear regression. Average sap nutrient levels at each growth stage for the top yielding quartile (the highest yielding 25% of all sites), bottom yielding quartile (the lowest yielding 25% of all sites) and the rest were calculated and compared to each other to define sap nutrient benchmarks. All

statistical analyses were conducted using GENSTAT Release 8.0 (Lawes Agricultural Trust, Rothamsted Experimental Station).

Results

Soil parameters

Indeterminate tomato crops

The average pH of topsoil (0-30cm) samples taken before the planting of trellis crops was 6.15 (S.D. ±0.29) (Table 1). Below 30 cm, the average pH before planting was 6.83 (S.D. ±0.16), rising to slightly alkaline below 60cm (7.69 ±0.30). Electrical conductivity (EC) ranged from 0.20 (S.D. ±0.04) to 0.35 (S.D. ±0.39) dS/m for samples taken before planting. Pre-planting nitrogen and phosphorus levels decreased markedly with soil depth, whereas potassium levels showed only a slight decline.

Table 1 Pre-planting soil analysis in commercial crops of indeterminate tomato cv Red Ruby from the 2003/4 and 2004/5 seasons in the Goulburn Valley. Standard deviations of values are expressed in terms of 95% confidence intervals (n=8).

	0-30 cm	30-60 cm	60-90 cm
PH (1:5 water)	6.15±$_{0.29}$	6.83±$_{0.16}$	7.69±$_{0.30}$
EC (dS/m)	0.20±$_{0.04}$	0.26±$_{0.21}$	0.35±$_{0.39}$
Total N (%)	0.15±$_{0.01}$	0.07±$_{0.01}$	0.03±$_{0.01}$
NH_4^+ (mg/kg)	17.25±$_{5.65}$	6.88±$_{1.11}$	4.93±$_{1.93}$
NO_3^- (mg/kg)	31.88±$_{17.65}$	15.13±$_{12.32}$	7.50±$_{4.53}$
PO_4^- (mg/kg)	15.06±$_{9.71}$	4.81±$_{1.88}$	2.54±$_{0.52}$
Total P (mg/kg)	45.88±$_{30.24}$	15.25±$_{6.76}$	7.63±$_{1.80}$
K (mg/kg)	322.00±$_{58.43}$	300.85±$_{59.61}$	289.13±$_{43.77}$

The post-harvest soil tests showed a pH drop at all measured depth intervals (Table 2), whereas electrical conductivity (EC) measurements increased in the topsoil. Post-harvest nitrogen (total, ammonium and nitrate) levels again decreased with depth, and ammonium levels were higher than before planting. Phosphate measurements also increased throughout the measured soil profile from pre-planting to post harvest, although the results were quite variable. Values for potassium also showed considerable variation, and showed no signs of depletion across the season.

Table 2 Post harvest soil analysis in commercial crops of indeterminate tomato cv Red Ruby between the 2003/4 and 2004/5 seasons in the Goulburn Valley. Standard deviations of values are expressed in terms of 95% confidence intervals (n=8).

	0-30 cm	30-60 cm	60-90 cm
pH (1:5 water)	5.95±0.37	6.39±0.21	7.16±0.34
EC (dS/m)	0.41±0.23	0.25±0.10	0.35±0.11
Total N (%)	0.17±0.02	0.09±0.03	0.05±0.01
NH_4^+ (mg/kg)	48.88±23.44	25.00±15.25	15.63±5.11
NO_3^- (mg/kg)	34.13±13.18	18.88±9.26	10.63±4.15
PO_4^- (mg/kg)	29.96±9.20	11.60±3.53	5.75±2.82
Total P (mg/kg)	92.75±32.90	37.88±11.50	22.75±17.02
K (mg/kg)	278.00±102.08	333.38±81.78	326.50±66.46

Determinate tomato crops

In determinate crops, soil pH values before planting ranged from 6.18 (S.D. ±0.31) in the topsoil (Table 3) to 6.98 (S.D. ±0.72) below 60cm. Electrical conductivity (EC) was low at 0.21 dS/m to 60cm, rising slightly to 0.34 (S.D. ±0.32) dS/m from 60-90cm. Pre-planting nitrogen (total, ammonium and nitrate) and phosphorus levels decreased with depth, whereas values for potassium were much higher, showed wide variation, and were similar at all three depths.

Table 3 Pre-planting soil analysis in commercial crops of determinate tomato cv Rebel for the 2004/05 season in the Goulburn Valley. Standard deviations of values are expressed in terms of 95% confidence intervals. (n=4)

	0-30 cm	30-60 cm	60-90 cm
pH (1:5 water)	6.18±0.31	6.63±0.72	6.98±0.72
EC (dS/m)	0.21±0.16	0.21±0.19	0.34±0.32
Total N (%)	0.21±0.09	0.11±0.07	0.07±0.04
NH_4^+ (mg/kg)	50.75±46.18	35.00±41.55	28.75±36.73
NO_3^- (mg/kg)	15.25±13.89	8.50±3.11	6.50±2.08
PO_4^- (mg/kg)	25.28±26.70	9.88±9.27	6.20±6.93
Total P (mg/kg)	85.25±92.25	36.00±38.55	20.50±22.29
K (mg/kg)	648.75±326.48	661.75±333.07	702.50±393.48

The post-harvest soil tests suggested a pH drop at the first two depths, with an increase at 60-90cm (Table 4). Electrical conductivity (EC) measurements increased slightly at all depth intervals in determinate crops, but the change was within the range of variation in the results. Post-harvest nitrogen (total, ammonium and nitrate) and phosphorus levels decreased with depth after harvest. Nitrate and ammonium N levels also fell slightly from pre-planting to post harvest measurements. Potassium levels showed a larger drop, although results were still quite variable.

Table 4 Post-harvest soil analysis in commercial crops of indeterminate tomato cv Rebel for the 2004/05 season in the Goulburn Valley. Standard deviations of values are expressed in terms of 95% confidence intervals. (n=4)

	0-30 cm	30-60 cm	60-90 cm
PH (1:5 water)	$6.00 \pm_{0.48}$	$6.28 \pm_{0.39}$	$7.73 \pm_{0.38}$
EC (dS/m)	$0.27 \pm_{0.13}$	$0.26 \pm_{0.08}$	$0.46 \pm_{0.13}$
Total N (%)	$0.25 \pm_{0.05}$	$0.13 \pm_{0.06}$	$0.08 \pm_{0.04}$
NH_4^+ (mg/kg)	$26.25 \pm_{22.17}$	$14.25 \pm_{5.38}$	$7.00 \pm_{3.37}$
NO_3^- (mg/kg)	$5.00 \pm_{4.24}$	$3.50 \pm_{1.73}$	$2.00 \pm_{1.41}$
PO_4^- (mg/kg)	$29.83 \pm_{24.92}$	$11.05 \pm_{7.67}$	$5.55 \pm_{3.80}$
Total P (mg/kg)	$96.25 \pm_{82.63}$	$38.75 \pm_{27.86}$	$19.50 \pm_{13.03}$
K (mg/kg)	$282.00 \pm_{94.52}$	$282.25 \pm_{24.65}$	$319.75 \pm_{125.44}$

An analysis of average soil nitrate levels over the three seasons of the project (2002/3-2004/5) showed that both pre-planting and post-harvest values decreased with depth. Nitrate levels increased from pre-plant to post harvest however, particularly in the shallower depths, presumably due to seasonal applications. (Figure 1).

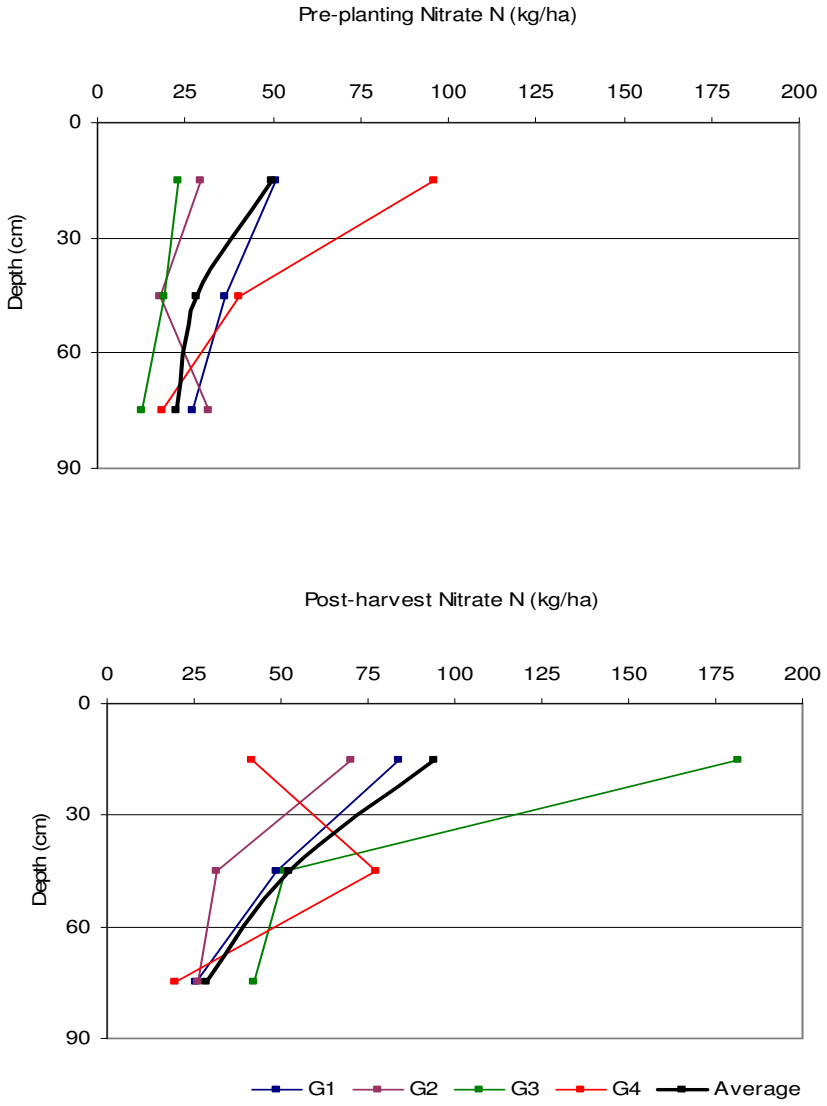


Figure 1 Pre-planting and Post-harvest soil nitrate within 0-90 cm in the commercial crops of indeterminate tomato cv Red Ruby for 2002/3-2004/5 seasons in the Goulburn Valley. Growers denoted as G1-G4.

Petiole sap analyses

Indeterminate tomato crops

Sap nutrient levels were measured at all sites (n=69) over four years and at four plant growth stages. Averaged over the four seasons, nitrogen levels dropped with growth stage of the plant, from 6048 ppm (S.D. ±702) at stage 1 down to 2458 ppm (S.D. ±752) at stage 4 (Figure 2A). Sap phosphorus levels also fell from an average of 258 ppm (S.D. ±91) at first and second flower stage down to 104 ppm (S.D. ±45) during the harvest (Figure 2B). Sap potassium levels tended to rise during crop growth, from an average of 4142 ppm (S.D. ±432) at stage 1 to 5262 ppm (S.D. ±860) at stage 4 (Figure 2C). Average sap calcium levels increased slightly, from 721 ppm (S.D. ±150) to 806 ppm (S.D. ±159) (Figure 2D), and a similar trend was

seen for magnesium (408 ppm to 518 ppm) (Figure 2E). As a trace element, zinc levels were low and varied with growth stages between seasons (Figure 2F). Standard deviations, represented as error bars in Figure 2, show that sap nutrient values for particular years were not widely dispersed from the average values for each growth stage.

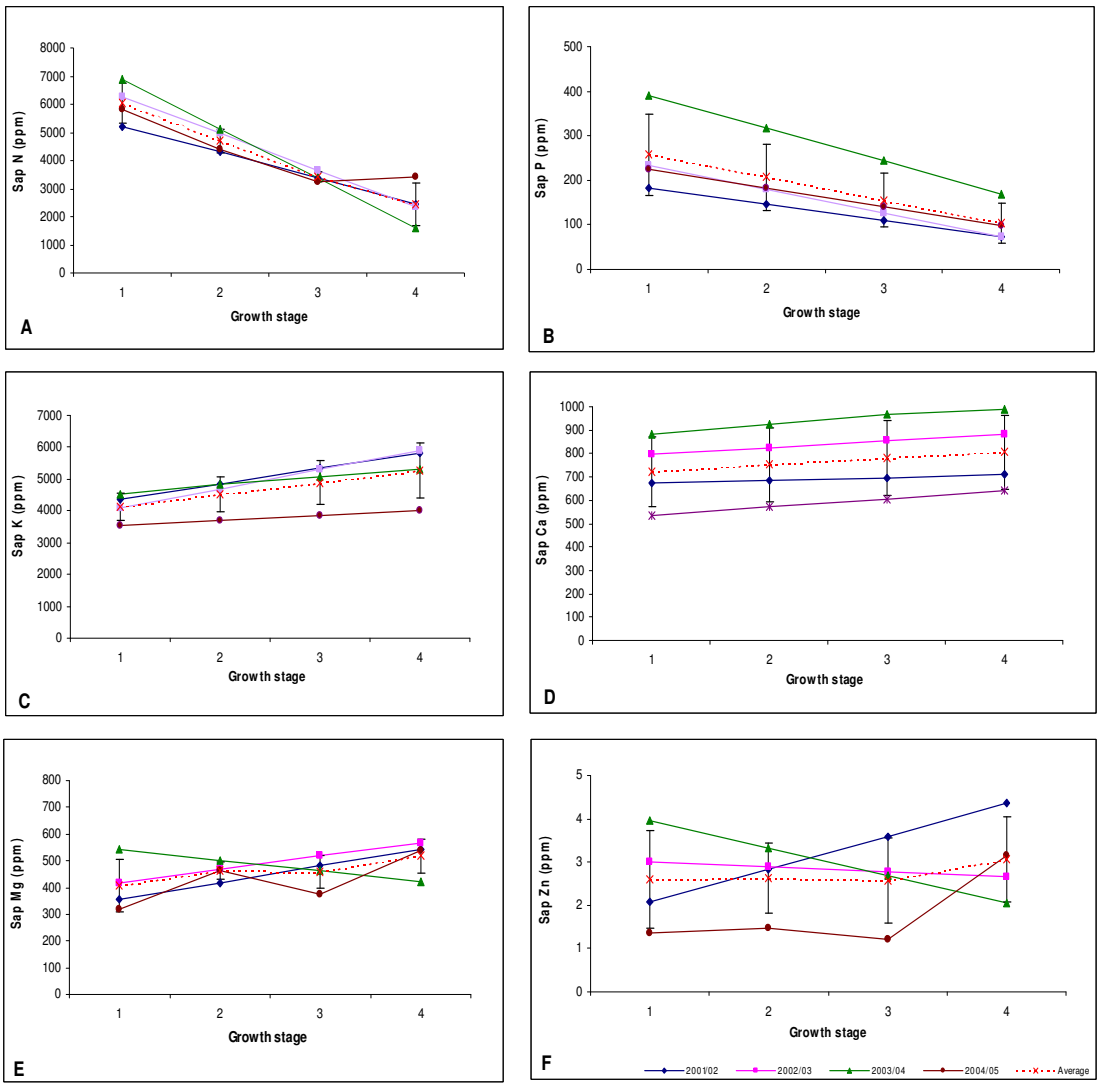


Figure 2 Average macro and micro (Zinc) nutrient levels from the top yielding quartiles at various growth stages in commercial crops of indeterminate tomato cv Red Ruby over four growing seasons in the Goulburn Valley. Standard deviations (at the 95% confidence level) are shown as error bars around the average values.

Yield and quality analysis

Indeterminate tomato crops

Total yields for the different sites over the four project seasons ranged from 88 to 228 t/ha for conventionally produced crops, averaging 162, 134, 111 and 116 t/ha for the four seasons respectively (Figure 3).

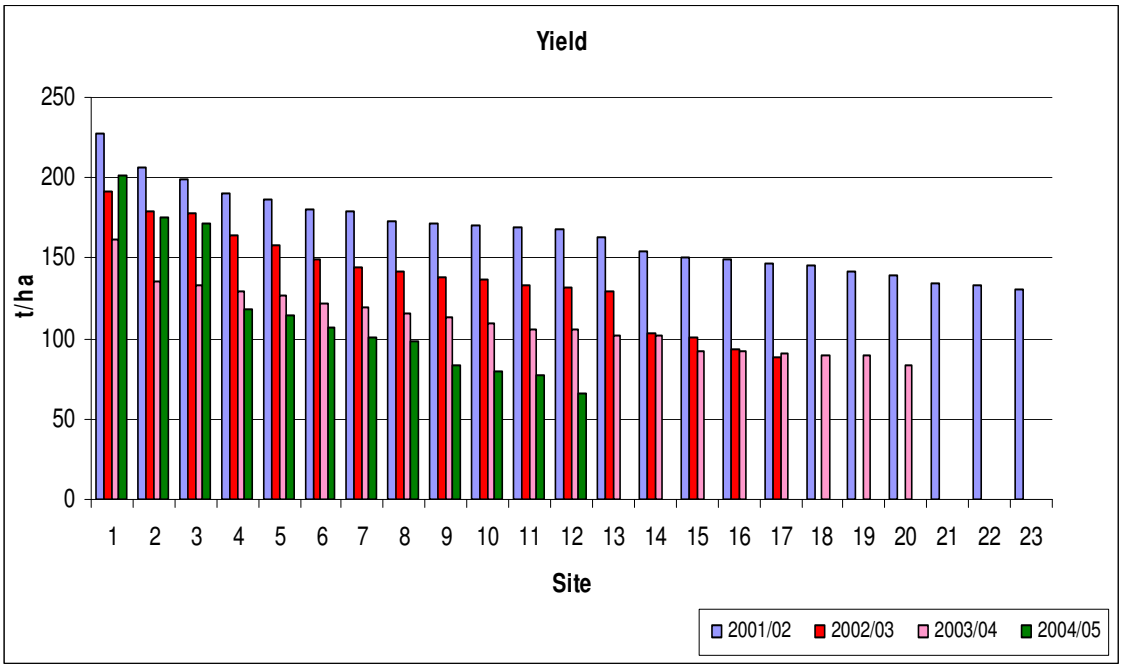
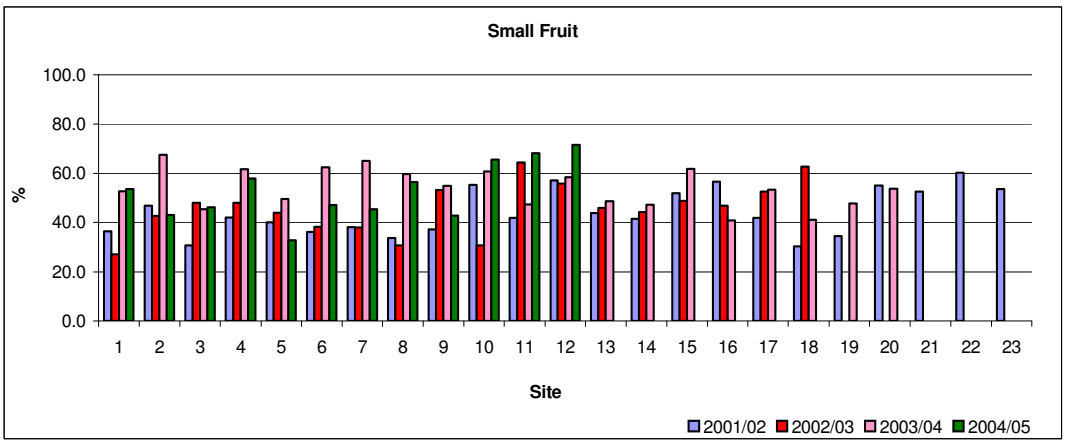
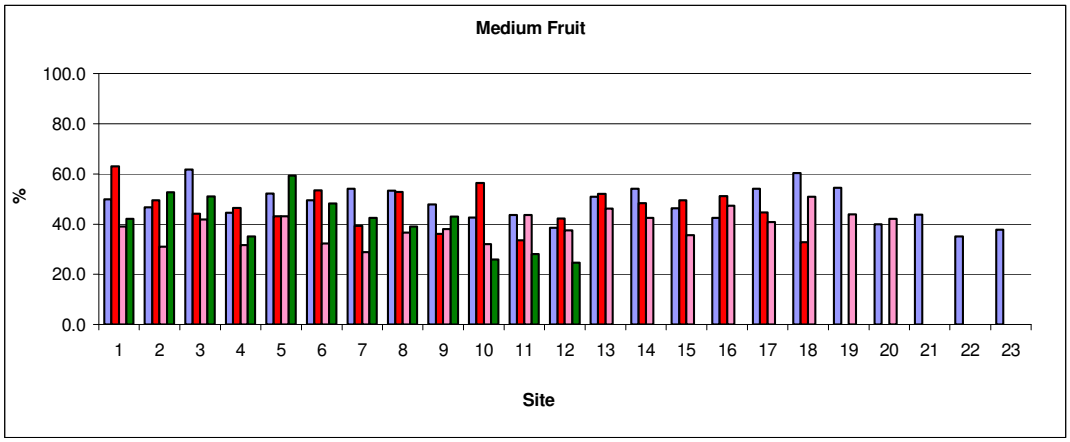


Figure 3 Total yields, measured from trial plots, in commercial crops of indeterminate tomato cv Red Ruby over four seasons (2001/2 – 2004/5) in the Goulburn Valley.

The average proportion of yield comprised by small fruit (<60mm diameter) ranged from 44.2 (2001/2) to 54.0% (2003/4). Similarly, values for the medium category (60-80mm) ranged from 39.3 (2003/4) to 48.2% (2001/2), and for large (>80mm) from 6.2 (2004/5) to 7.8% (2003/4). (Figure 4)

The yield of unmarketable fruit from the monitored sites ranged from 7.0 to 55.5% of the total harvest (Figure 5). Soluble solids values ranged largely between 4.0 and 5.0%, while the firmest fruit were found in 2001/2 (1.09 mm), and the softest in 2004/5 (1.34 mm).





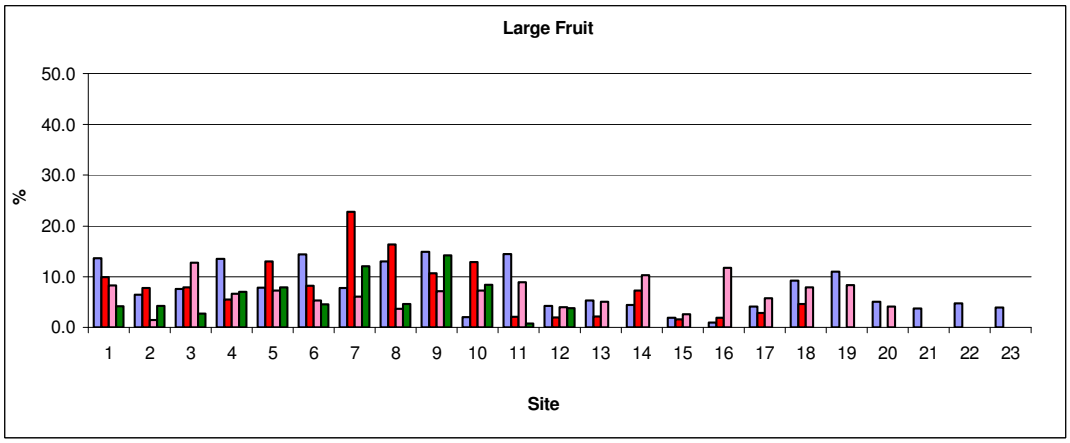
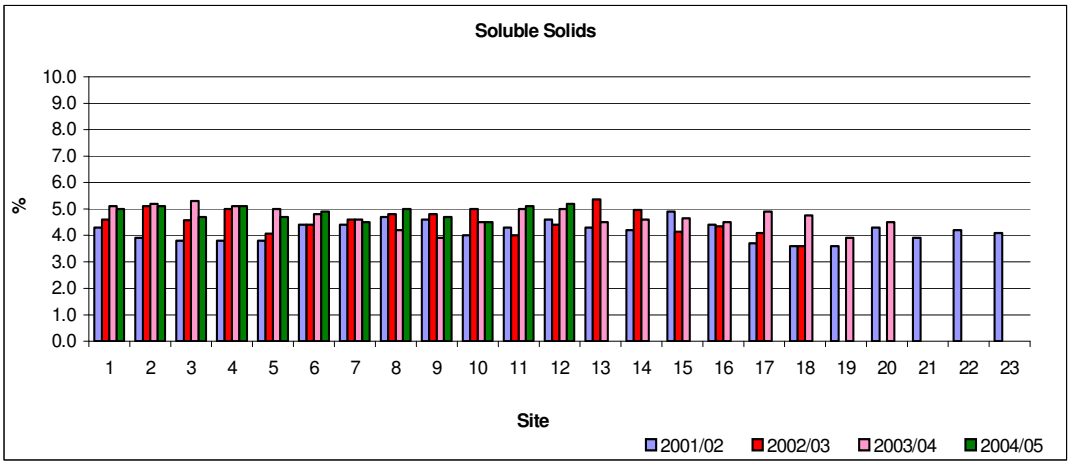
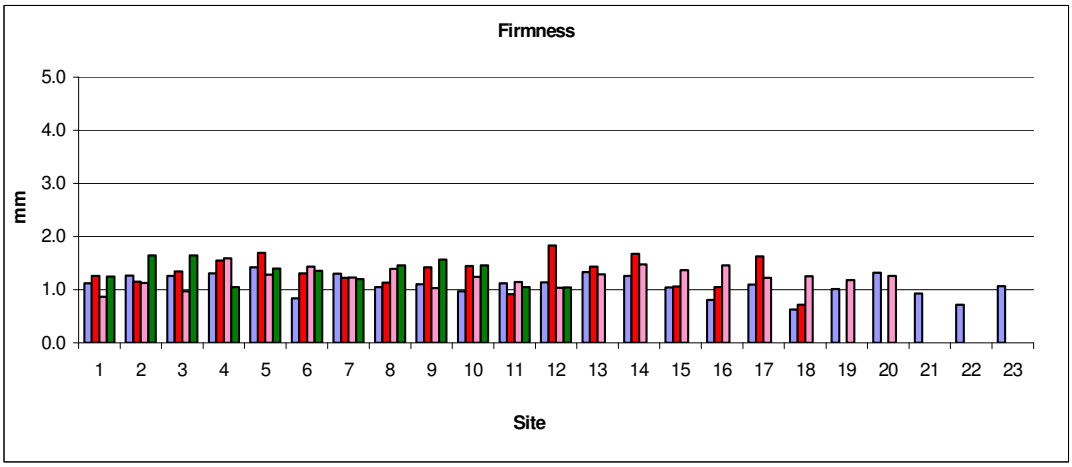


Figure 4 Fruit size (as a percentage by weight of the total yield) in yields from plot harvests in commercial crops of indeterminate tomato cv Red Ruby over four seasons (2001/2 – 2004/5) in the Goulburn Valley. Small fruit are defined as having a diameter of less than 60mm, medium 60-80mm and large >80mm.





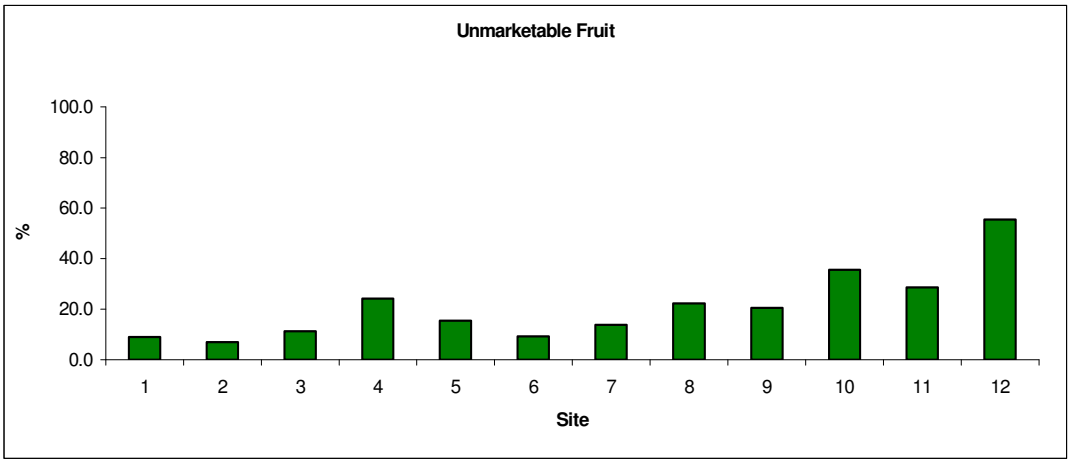


Figure 5 Soluble solids (%), firmness (mm compression) and unmarketable fruit (as a percentage by weight of the total yield) from plot harvests in commercial crops of indeterminate tomato cv Red Ruby over four seasons (2001/2 – 2004/5) in the Goulburn Valley. Unmarketable fruit yields were recorded for the 2004/05 season only.

Determinate tomato crops

Total yields for determinate crops in the 2004/5 season, ranged from 110 to 228 t/ha with an average of 145.3 t/ha (Figure 6).

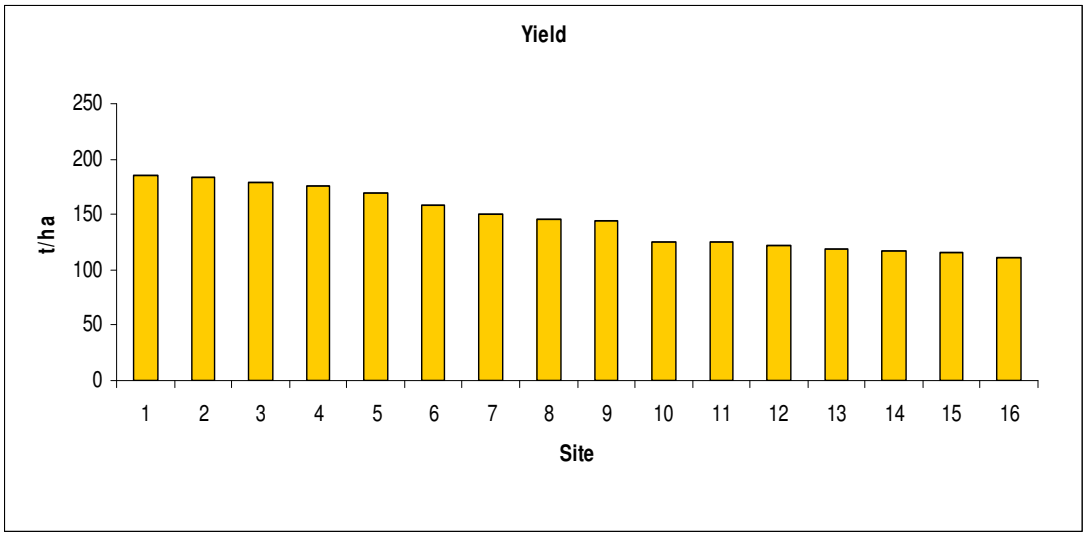


Figure 6 Yields from trial plots in commercial crops of determinate tomato cv Rebel in the 2004/05 season in the Goulburn Valley.

The proportion of yield made up of small fruit ranged from 11.8 to 37.8%, medium from 41.2 to 56.6%m and large from 15.6 to 39.0% (Figure 7). Unmarketable fruit made up from 17.5 to 29.3% of the total yield. Soluble solids varied between sites from 4.20% to 5.30%, while fruit firmness averages ranged from 1.10 mm to 2.20 mm with an average of 1.39 mm (Figure 8).

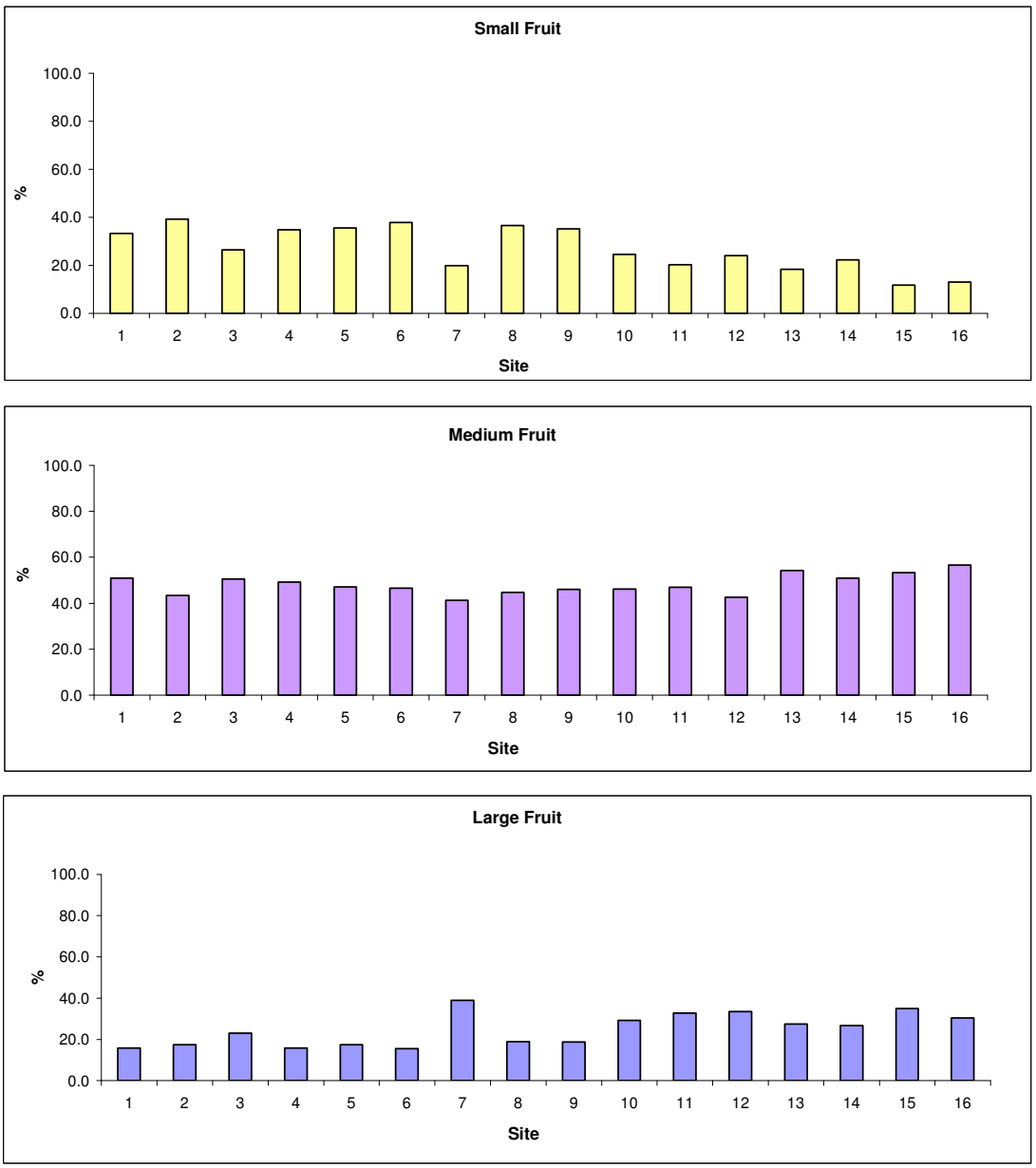


Figure 7 Fruit size components in commercial crops of determinate tomato cv Rebel from the 2004/05 season in the Goulburn Valley. Small fruit are defined as having a diameter of less than 60mm, medium 60-80mm and large >80mm.

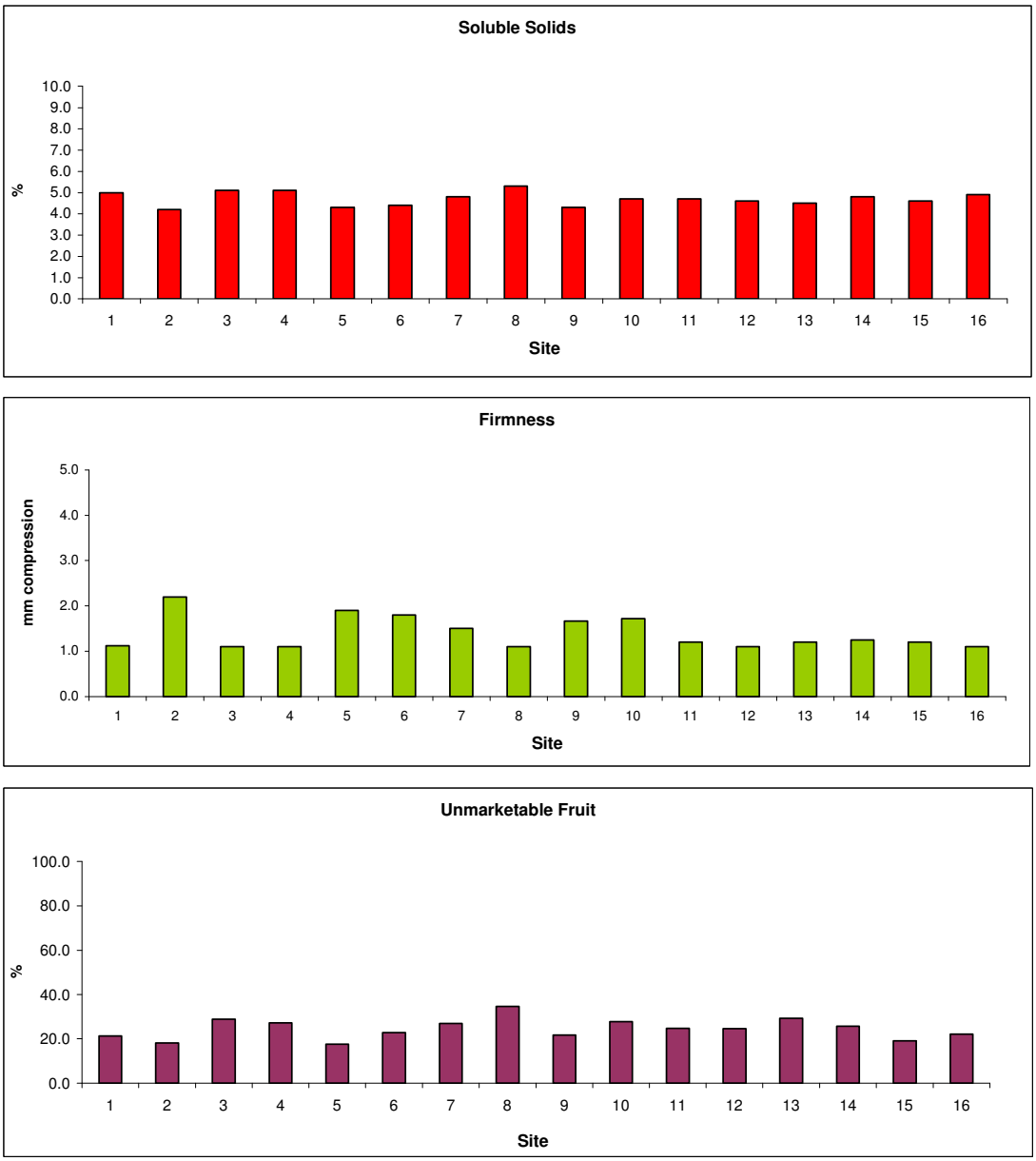


Figure 8 Soluble solids (%), firmness (mm compression) and unmarketable fruit (as a percentage by weight of the total yield) from plot harvests in commercial crops of determinate tomato cv Rebel from the 2004/05 season in the Goulburn Valley.

Relationships between sap nutrient levels and fruit yield and fruit parameters

The relationships between sap nutrient levels at four growth stages and yield and quality attributes were examined through linear regression analysis. The validity of results from the first three seasons, where there was no replication within sites, was tested in the final year, with replication (x4) at four sites. Significant relationships ($p<0.05$), both positive and negative, were found between nutrient levels and total yield and fruit quality parameters at all growth stages. In describing the data set and discussion of significant relationships, emphasis is placed on yield as well as the small and large fruit components – as these are likely to be of greatest commercial significance.

Indeterminate tomato crops

When data from the first three seasons was combined (Table 5), negative relationships were found between nitrogen levels and yield for the first three growth stages. This suggests that high nitrogen levels may have a detrimental affect on yield. On the other hand, a significant positive relationship was evident between potassium levels and total yield at the third growth stage. Effects of magnesium and calcium were not as strong, but negative relationships were evident at $p<0.1$.

Significant ($p<0.05$) relationships between sap nutrient levels and fruit size were also found at various growth stages (Table 5). Small fruit % was positively related to nitrogen levels at stages 2 and 3, and magnesium at stage 2. Phosphorus was negatively related to medium% at all growth stages. Potassium positively related to medium% at stage 2 and large% fruit at stage 3. There were significant negative relationships between calcium and medium% fruit at stages 2 and 4, but at stages 1 and 4, calcium was positively related to large%.

Table 5. The significance and nature of relationships between petiole sap nutrient levels at four growth stages, and fruit yield and size from commercial sites of indeterminate tomato cultivar Red Ruby. Data are combined for the seasons 2001/2, 2002/3 and 2003/4 (n = 168).

	Yield t/ha				Small%				Medium%				Large %			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
N	**0.003**	**0.005**	**0.033**	0.518	0.079	**0.027**	**0.019**	0.934	0.191	**0.013**	0.668	**0.010**	0.111	0.686	0.292	0.585
P	0.845	0.445	0.493	0.860	0.328	0.053	0.099	0.159	**0.044**	**0.003**	**0.031**	**0.018**	0.116	0.269	0.792	0.228
K	0.360	0.781	**0.011**	0.178	0.576	0.072	0.857	0.456	0.966	**0.021**	0.192	0.484	0.205	0.847	**0.029**	0.686
Ca	0.159	0.066	0.190	0.670	0.827	0.087	0.411	0.506	0.178	**0.014**	0.429	**0.045**	**0.030**	0.523	0.684	**0.018**
Mg	0.065	0.074	0.379	0.112	0.183	**0.034**	0.316	0.321	0.162	0.082	0.836	0.753	0.673	0.110	**0.042**	0.075
Zn	0.929	0.147	0.112	0.090	0.725	0.771	**<.001**	0.345	0.855	0.343	**<.001**	0.156	0.576	0.238	0.227	0.602

Black and Red coloured figures indicate positive and negative relationships respectively.

There were few significant ($p<0.05$) relationships between sap nutrient levels and either firmness or soluble solids content of fruit. A negative relationship was found between magnesium and fruit firmness at growth stage 2 (Table 6). Soluble solids content was related to zinc positively at stage 1, but negatively at stage 4.

Table 6 The significance and nature of the relationships between petiole sap nutrient levels and fruit firmness and soluble solids at four growth stages from commercial sites of indeterminate tomato cultivar Red Ruby. Data are combined over the 2001/2, 2002/3 and 2003/4 seasons(n = 168).

	Firmness mm				Soluble Solids %			
	1	2	3	4	1	2	3	4
N	0.490	0.732	0.201	0.289	0.937	0.309	0.919	0.553
P	0.412	0.995	0.518	0.951	0.569	0.775	0.929	0.411
K	0.354	0.765	0.087	0.883	0.625	0.057	0.454	0.317
Ca	0.660	0.786	0.207	0.199	0.353	0.310	0.074	0.903
Mg	0.213	**0.016**	0.405	0.953	0.422	0.604	0.129	0.880
Zn	0.575	0.211	0.735	0.399	**0.012**	0.792	0.145	**0.037**

Black and Red coloured figures indicate positive and negative relationships respectively.

In 2004/5, significant negative relationships were found between nitrogen levels and yield at growth stage 1. Similarly, sap phosphorus (stages 3 and 4) and potassium (stage 1) levels were negatively related to yield (Table 7). Calcium was positively related to yield at growth stage 2, and potassium, calcium, magnesium and sulphur all showed a positive relationship to yield at stage 4.

Significant positive relationships were found between small% and sap nitrogen at stage 1, and phosphorus at stage 4. On the other hand, small% was negatively related to potassium and magnesium at stage 4. Nitrogen and phosphorus were negatively related, while magnesium and sulfur were positively related to medium% at stage 4. Large% was related negatively to nitrogen, potassium, calcium and sulphur at stage 2, but positively to phosphorus, potassium, magnesium and sulfur at stage 3 (Table 7).

Table 7 The significance and nature of relationships between petiole sap macronutrient levels and fruit yield and size, from four growth stages in commercial crops of indeterminate tomato cultivar Red Ruby sampled during the 2004/05 season (n=48).

	Yield t/ha				Small%				Medium%				Large %			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
N	**0.023**	0.107	0.231	0.125	**0.008**	0.278	0.944	0.055	**0.010**	0.754	0.856	**0.033**	0.361	**<.001**	0.726	0.968
P	0.130	0.452	**0.048**	**0.005**	0.287	0.167	0.893	**0.049**	0.371	0.335	0.398	**0.011**	0.284	0.092	**0.038**	0.667
K	**0.003**	0.419	0.325	**0.047**	0.058	0.130	0.253	**0.033**	**0.031**	0.511	0.766	0.058	0.861	**<.001**	**<.001**	0.257
Ca	0.533	**0.025**	0.612	**<.001**	0.711	0.710	**0.014**	0.669	0.663	0.293	**0.046**	0.301	0.926	**0.039**	0.111	0.097
Mg	0.092	0.661	0.602	**0.004**	0.818	0.854	0.071	**0.006**	0.573	0.837	0.395	**<.001**	**0.005**	0.241	**<.001**	0.986
S	0.187	0.462	0.604	**0.002**	0.977	**0.016**	0.277	0.141	0.532	0.036	0.783	**0.027**	0.095	**0.002**	**0.001**	0.197

Black and Red coloured figures indicate positive and negative relationships respectively.

Yield was found to be negatively related to boron (stages 3 and 4), manganese and zinc (both at stages 2 and 3). The proportion of small fruit in the total yield was positively related to boron at stage 3, but negatively related to zinc at stage 4. Relationships for medium fruit percentage were the opposite of those for small – ie negative for Boron at stage 3, but positive for zinc at stage 4. The percentage of large fruit had a positive relationship with all micronutrients at stage 1, with iron at stage 2, with copper and iron at stage 3 and with copper at stage 4. The only negative relationship found for large% and micronutrients was for boron at stage 2 (Table 8).

Table 8 The significance and nature of relationships between petiole sap micronutrient levels and fruit yield and size, from four growth stages in commercial crops of indeterminate tomato cultivar Red Ruby sampled during the 2004/05 season (n=48).

	Yield t/ha				Small%				Medium%				Large %			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
B	0.154	0.504	**0.004**	**0.006**	0.628	0.211	**0.034**	0.223	0.847	0.602	**0.008**	0.053	**0.021**	**0.003**	0.407	0.185
Cu	0.142	0.325	0.111	0.062	0.497	0.052	0.544	0.884	0.898	0.118	0.817	0.399	**0.001**	0.202	**0.002**	**0.021**
Fe	0.202	0.052	0.143	0.148	0.247	0.778	0.548	0.117	0.748	0.681	0.852	0.081	**<.001**	**0.015**	**0.003**	0.792
Mn	0.079	**0.004**	**<.001**	0.939	0.643	0.262	0.268	0.290	0.739	0.089	0.063	0.485	**0.003**	0.712	0.528	0.160
Zn	0.398	**0.010**	**0.021**	0.777	0.398	0.694	0.256	**0.014**	0.976	0.336	0.088	**0.032**	**0.001**	0.134	0.251	0.249

Black and Red coloured figures indicate positive and negative relationships respectively.

In the 2004/05 season, the proportion of unmarketable fruit in the total yield was also estimated and its relationship tested with both macro and micronutrients (Table 9). For the macronutrients, significant positive relationships were identified at stages 1 (N and K) and 4 (P), with negative relationships at stages 3 (Ca) and 4 (K, Mg and S). Most micronutrients were positively related to % unmarketable fruit at stages 2 and 3.

Table 9. Significance and nature of relationships between petiole sap nutrient levels and unmarketable yield % at four growth stages from commercial sites of indeterminate tomato cv. Red Ruby sampled during the 2004/05 season (n = 48).

	Macronutrients					Micronutrients			
	1	2	3	4		1	2	3	4
N	**0.007**	0.621	0.930	0.054	**B**	0.505	0.998	**0.018**	0.087
P	0.378	0.298	0.381	**0.025**	**Cu**	0.717	**0.007**	0.639	0.281
K	**0.001**	0.671	0.954	**0.003**	**Fe**	0.982	0.388	0.620	0.133
Ca	0.578	0.066	**0.004**	0.055	**Mn**	0.461	**0.007**	**0.004**	0.431
Mg	0.486	0.630	0.410	**0.012**	**Zn**	0.783	**0.050**	**0.006**	0.162
S	0.425	**0.006**	0.922	**0.012**					

Black and Red coloured figures indicate positive and negative relationships respectively.

Determinate tomato crops

In data collected from the 2004/05 season only, yield of determinate crops was positively related to Phosphorus at stages 1 and 4, and to potassium at stage 1. Negative relationships were more common, with nitrogen and calcium at stage 1, magnesium at stage 2, and calcium and magnesium at stage 4 (Table 10). Many significant relationships were identified between petiole nutrient content and fruit size components. Most notable were that Phosphorus content was positively related to small%, and negatively related to large% at most growth stages. Large fruit percentage was also positively related to potassium at stage 3, and magnesium at stage 4, but negatively related to nitrogen at stage 3 and calcium at stages 3 and 4.

Table 10 The significance and nature of the relationships between petiole sap macronutrient levels and fruit yield and size at four growth stages from commercial sites of determinate tomato cv. Rebel sampled during the 2004/05 season. (n = 64).

	Yield t/ha				Small%				Medium%				Large %			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
N	0.009	0.911	0.240	0.540	0.430	0.283	0.051	0.516	0.833	0.183	0.558	<.001	0.305	0.617	0.006	0.403
P	0.001	0.130	0.138	0.003	<.001	0.009	0.060	0.011	0.375	0.319	0.533	0.358	<.001	0.019	0.007	<.001
K	0.029	0.890	0.087	0.726	0.596	0.457	0.112	0.257	0.040	0.575	0.139	0.008	0.614	0.588	0.003	0.986
Ca	0.049	0.104	0.489	0.008	0.022	0.186	0.457	<.001	0.102	0.025	0.017	0.380	0.087	0.731	0.026	<.001
Mg	0.293	0.019	0.059	0.012	0.234	0.101	0.423	<.001	0.454	<.001	0.342	0.139	0.342	0.835	0.692	0.005
S	0.202	0.879	0.591	0.003	0.144	0.691	0.211	0.004	0.107	0.018	0.003	0.020	0.005	0.085	0.981	<.001

Black and Red coloured figures indicate positive and negative relationships respectively.

Data analysis also revealed many significant ($p<0.05$) relationships between petiole micronutrient levels and yield in determinate crops (Table 11). Manganese in particular was negatively related to yield at three growth stages (1, 2 and 4). A significant positive relationship was evident between copper and yield at stages 2 and 3, and at stage 4, all the micronutrients were significantly related to yield. Similar relationships were found between these nutrients and small% at stage 4, which also featured equally significant, but opposite relationships for most micronutrients and large%. Large fruit % was positively related to manganese at all four growth stages, to boron at stage 2 and iron at stages 3 and 4.

Table 11 The significance and nature of relationships between petiole sap micronutrient levels and fruit yield and size components at four growth stages from commercial sites of determinate tomato cv. Rebel sampled during the 2004/05 season (n = 64).

	Yield t/ha				Small%				Medium%				Large %			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
B	0.380	0.058	0.547	0.003	0.843	0.003	0.845	<.001	0.136	0.089	0.163	0.866	0.572	0.026	0.325	<.001
Cu	0.269	0.030	0.044	0.018	0.216	0.005	0.250	0.047	0.025	0.463	0.853	0.045	0.803	0.006	0.214	0.263
Fe	0.640	0.143	0.053	0.001	0.198	0.288	0.032	<.001	0.025	0.016	0.954	0.890	0.115	0.995	0.009	<.001
Mn	0.006	0.002	0.085	<.001	0.003	<.001	0.014	<.001	0.121	0.002	0.640	0.181	0.019	0.045	<.001	<.001
Zn	0.009	0.086	0.389	0.327	0.693	0.049	0.881	0.842	0.229	<.001	0.291	0.064	0.836	0.679	0.453	0.221

Black and Red coloured figures indicate positive and negative relationships respectively.

Relationships between unmarketable yield% and petiole nutrient levels are shown in Table 12. Positive relationships were found for nitrogen and potassium at stage 1, zinc, copper, manganese and sulphur at stage 2, zinc, boron and manganese at stage 3 and Phosphorus at stage 4. Negative relationships were only evident in the last two growth stages, with calcium at stage 3 and potassium, magnesium and sulphur at stage 4.

Table 12 The significance and nature of relationships between petiole sap nutrient levels at four growth stages and unmarketable yield % from commercial sites of indeterminate tomato cv. Rebel sampled during the 2004/05 season (n = 64).

	Macronutrients					Micronutrients			
	1	**2**	**3**	**4**		**1**	**2**	**3**	**4**
N	**0.007**	0.621	0.930	0.054	**B**	0.505	0.998	**0.018**	0.087
P	0.378	0.298	0.381	**0.025**	**Cu**	0.717	**0.007**	0.639	0.281
K	**0.001**	0.671	0.954	**0.003**	**Fe**	0.982	0.388	0.620	0.133
Ca	0.578	0.066	**0.004**	0.055	**Mn**	0.461	**0.007**	**0.004**	0.431
Mg	0.486	0.630	0.410	**0.012**	**Zn**	0.783	**0.050**	**0.006**	0.162
S	0.425	**0.006**	0.922	**0.012**					

Black and Red coloured figures indicate positive and negative relationships respectively.

Critical sap nutrient levels based on the top and bottom yielding quartiles

The data on crop yields was separated into quartiles (ie four equal groups) based on yield, and average values for the top (highest yielding) quartile were used as "benchmark" petiole nutrient levels. Three contrasts were evaluated: the top quartile (TQ) versus the bottom quartile (BQ), the top quartile versus the rest (R) and the bottom quartile versus the rest. Comparisons between average petiole nutrient levels from the top and bottom quartiles are summarised in the following figures.

Indeterminate tomato crops

Results from seasons 2001/2, 2002/3 and 2003/4 (Figure 9) showed that top quartile averages for nitrogen were lower than those for the bottom quartile for all growth stages, although a significant difference was only found at stage 3 ($p<0.05$). The opposite was found for phosphorus (ie TQ levels were higher), with a significant difference only at stage 2 ($p<0.05$). No other significant differences were found between top and bottom quartile nutrient levels**.**

The top quartile average for potassium was lower at stages 1 and 2 but slightly higher at stage 4 than that for the bottom quartile. Top quartile calcium values were lower than those for the bottom quartile at stages 1 and 4, whereas magnesium values were higher at stages 3 and 4.

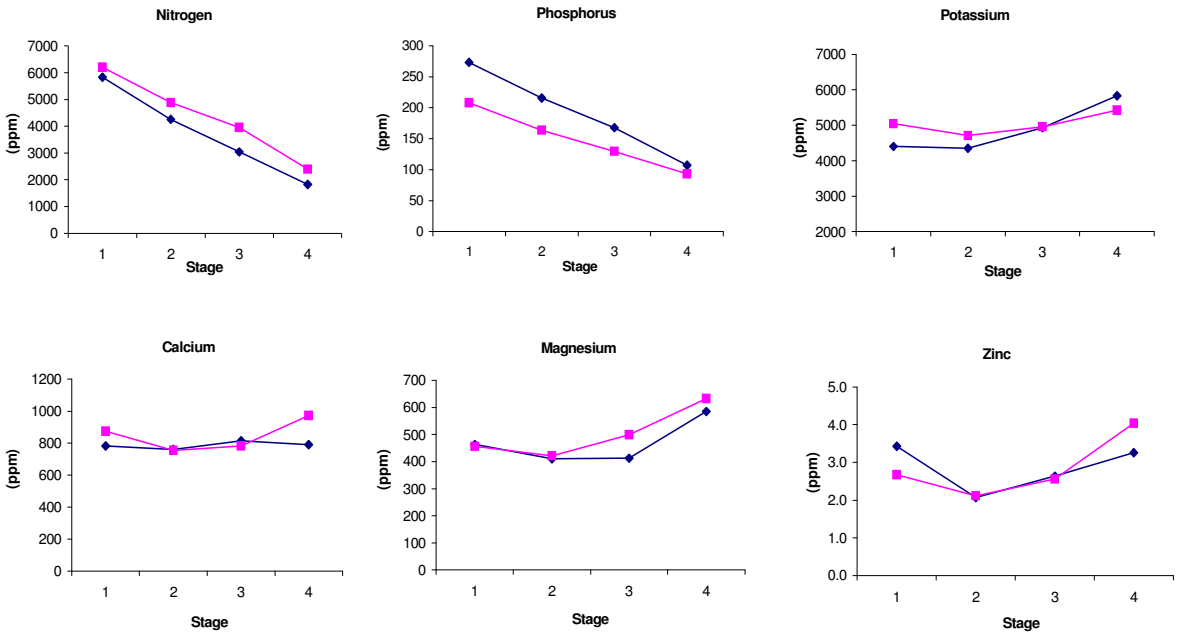


Figure 9 Petiole sap macronutrient (and Zn as micronutrient) levels for top and bottom yielding quartiles of commercial crops of the indeterminate tomato cv Red Ruby from three seasons (2001/02-2003/04) in the Goulburn Valley (♦TQ and ■ BQ).

In the 2004/05 season when measurements were replicated within sites, many significant differences were found between the average nutrient levels from the top and bottom quartiles (Figure 10). The critical level for nitrogen was significantly lower than the BQ average for all crops during growth stages 1 and 4. For Phosphorus critical levels were lower than those for the bottom quartile at all growth stages.

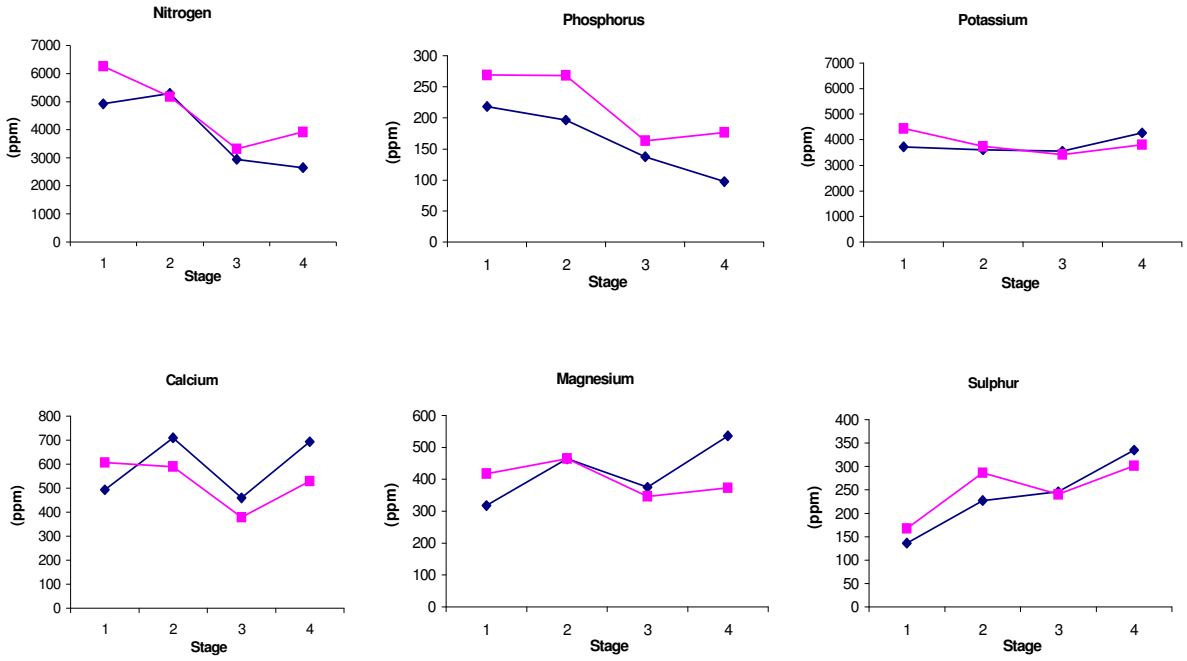


Figure 10 Average concentrations of macronutrients in petioles from top and bottom yielding quartiles of commercial crops of indeterminate tomato cv Red Ruby from the 2004/05 season in the Goulburn Valley (♦TQ and ■ BQ).

Sap potassium levels were significantly different at stages 1, 2 and 4. Calcium levels for the top quartile were significantly higher than BQ values at stages 2 and 4, but lower at stage 1. Critical levels for magnesium were significantly lower at stage 1 but higher at stage 4 than BQ averages.

Critical levels for micronutrients were also estimated for the 2004/05 season (Figure 11). Boron, copper, iron and manganese values were all found to be lower than the bottom quartile averages at all growth stages, although not all differences were significant ($p<0.05$). The averages were significantly different for boron at stages 1, 3 and 4; for copper at stages 2,3 and 4; iron at stages 2 and 4; and manganese at stages 1, 2 and 3. Sap zinc levels were significant different between top and bottom quartiles at all growth stages.

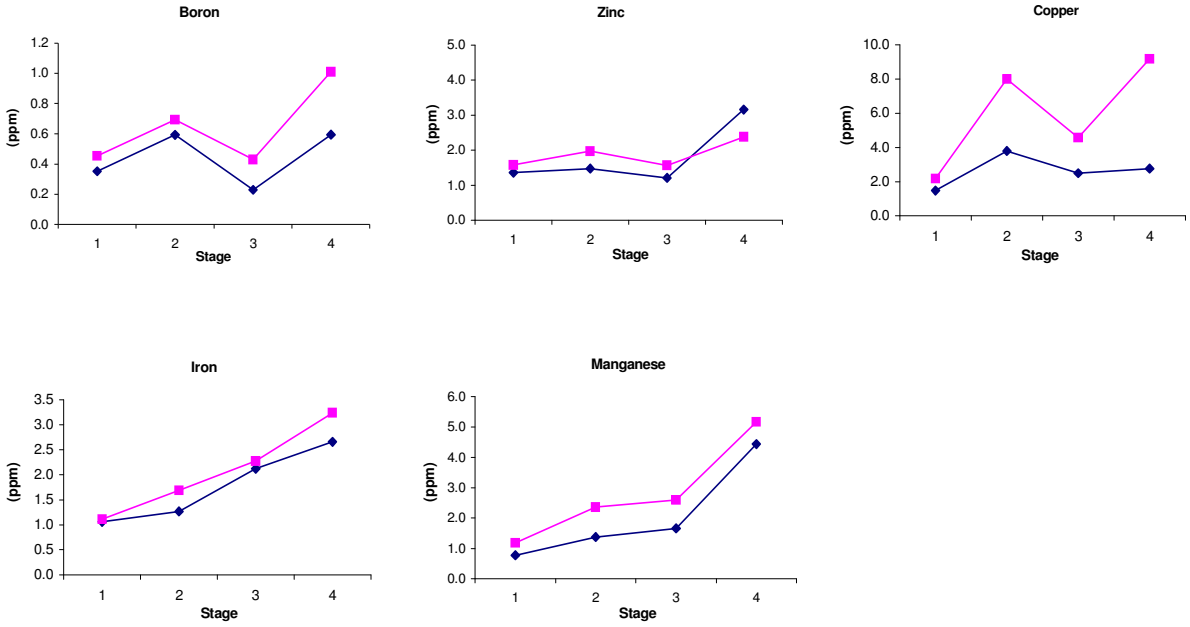


Figure 11 Micronutrients in petioles from top and bottom yielding quartiles of commercial crops of the indeterminate tomato cv Red Ruby from the 2004/05 season in the Goulburn Valley (♦TQ and ■ BQ).

There were no significant differences in fruit size components between the top and bottom quartiles in trellis crops monitored over the first three years. Similarly, firmness and soluble solids results revealed no significant differences between the top and bottom quartiles (Figure 12).

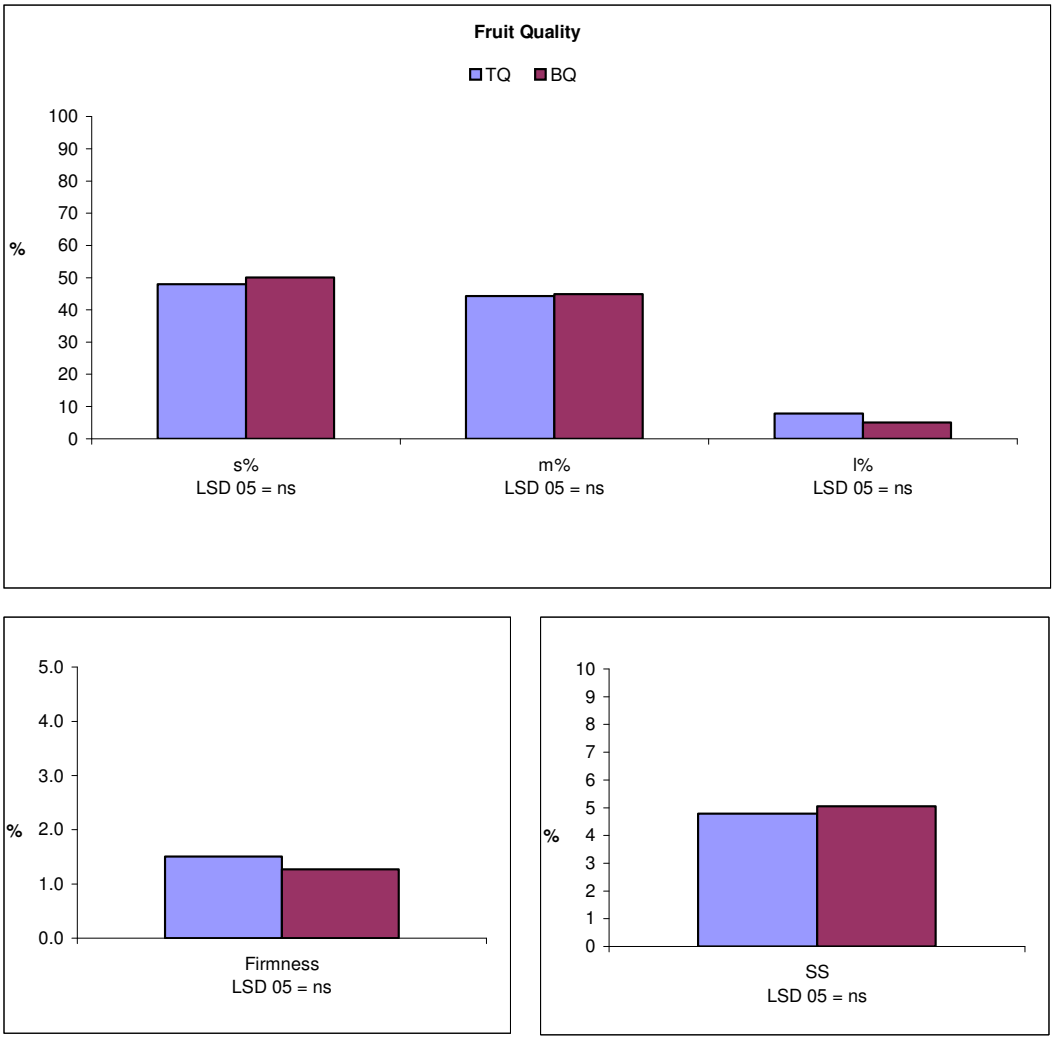


Figure 12 Fruit quality components from the top (TQ) and bottom (BQ) yielding quartiles of commercial crops of the indeterminate tomato cv Red Ruby from the first three seasons in the Goulburn Valley. Small fruit are <60mm in diameter, medium 60-80mm, large >80mm. LSD = Least Significant Difference at 5%.

In results from the 2004/05 season, significant differences were found between the top and bottom quartiles for small, medium and unmarketable fruit from indeterminate crops (Figure 13). The top yielding quartile had significantly less fruit in the small category (47.5% cf. 63.5%), but more mediums (48.6% cf 31.7%). The proportion of unmarketable fruit in the top quartile (9.1%) was also significantly less than that in the bottom quartile (32.7%).

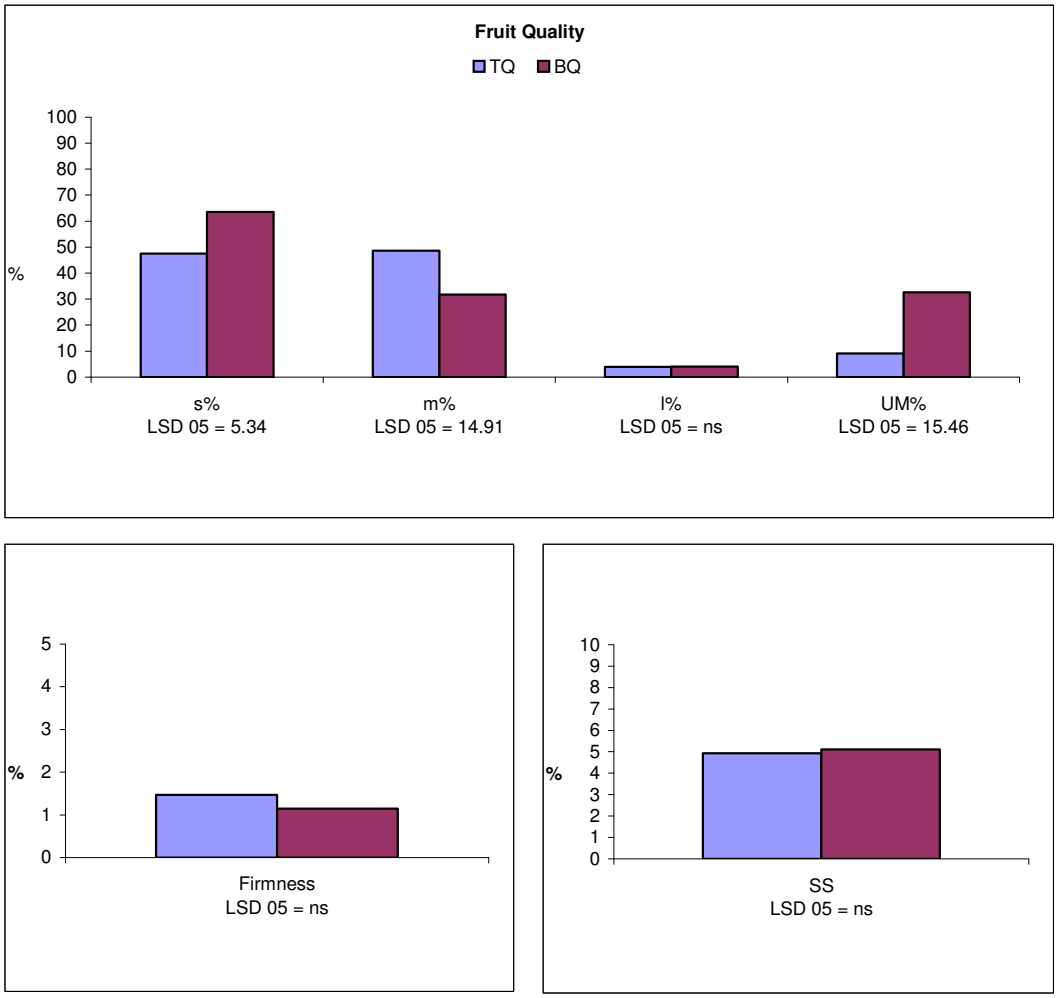


Figure 13 Fruit size, firmness and soluble solids components from the top (TQ) and bottom (BQ) yielding quartiles of commercial crops of the indeterminate tomato cv Red Ruby from the 2004/05 season in the Goulburn Valley. Small fruit are <60mm in diameter, medium 60-80mm, large >80mm. LSD = Least Significant Difference at 5%.

Determinate tomato crops

In determinate crops measured during the 2004/05 season, critical levels for nitrogen were significantly different to the averages for the bottom quartile at all growth stages – being higher at stage 1, but lower thereafter (Figure 14). Critical levels for Phosphorus were significantly higher than BQ values for stages 1 and 4, whereas levels for potassium were higher at stage 1 only. Petiole calcium levels were lower in the top quartile at growth stages 1, 2 and 4. There were also significant differences for magnesium at stages 2, 3 and 4, and for sulphur at stages 2 and 4.

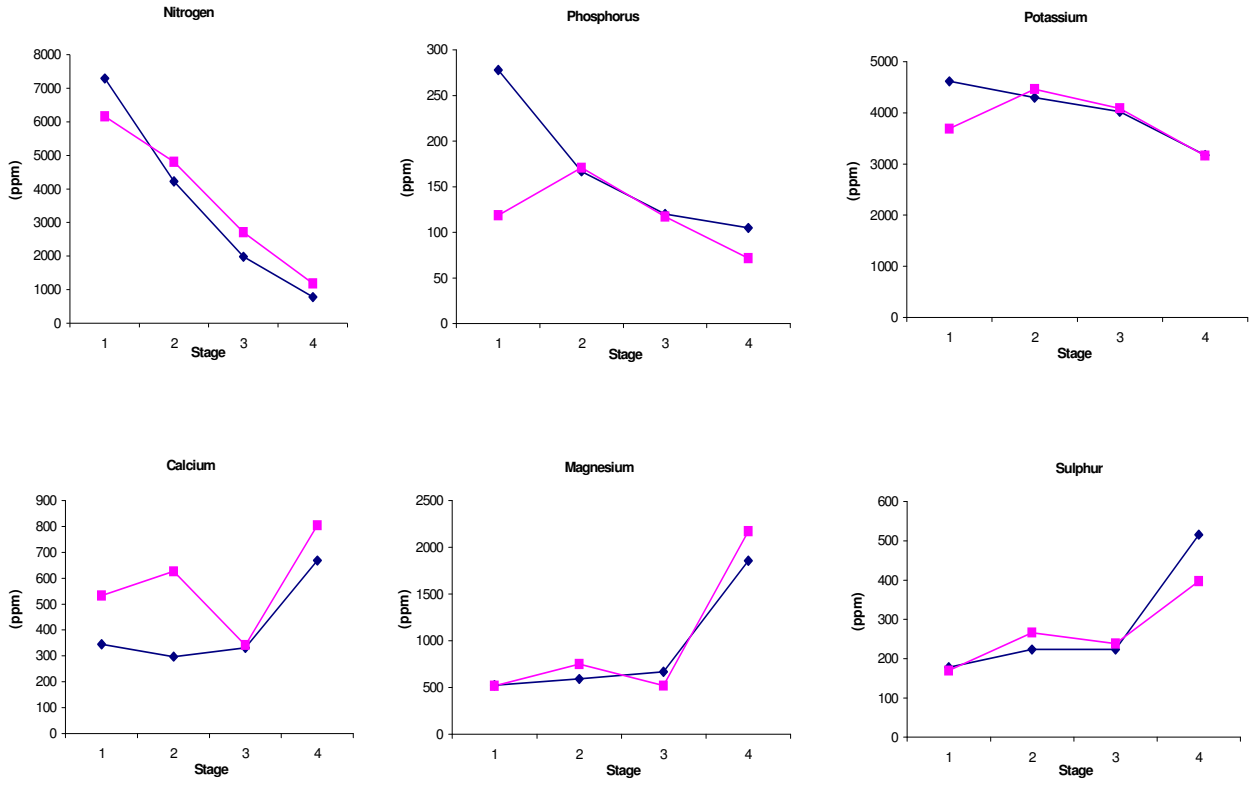


Figure 14 Macronutrient concentrations in petioles from top and bottom yielding quartiles of commercial crops of the determinate tomato cv Rebel from the 2004/05 season in the Goulburn Valley (♦TQ and ■ BQ).

Critical levels for trace elements were also calculated for determinate crops in the 2004/05 season (Figure 15). Critical values for boron, iron and manganese were generally lower than bottom quartile averages at the various growth stages. Significant differences were identified at all stages for boron, iron, copper and zinc; and at stages 1, 2 and 4 for manganese.

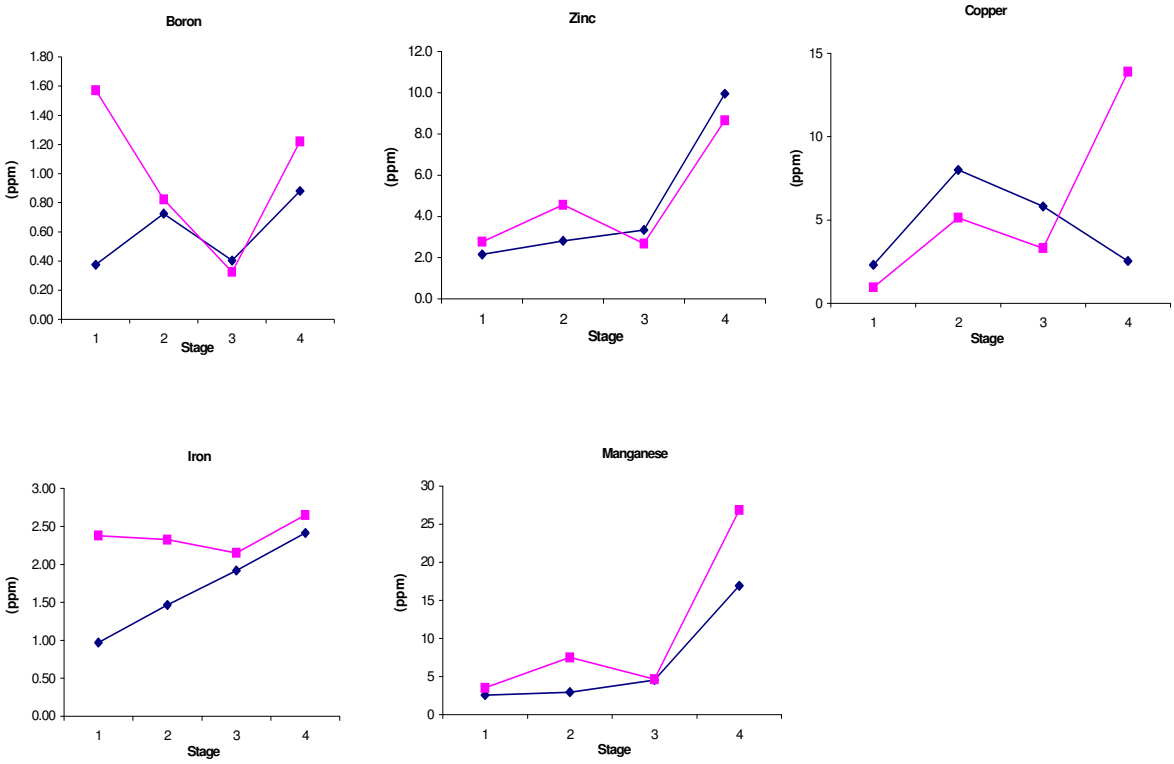


Figure 15 micronutrient concentrations in petioles from top and bottom yielding quartiles from commercial crops of the determinate tomato cv Rebel from the 2004/05 season in the Goulburn Valley (♦TQ and ■ BQ).

In the 2004/05 season, significant differences were also found between top and bottom quartiles for small, medium and large fruit in determinate crops (Figure 16). The top yielding quartile (32.7%) had more small fruit than the bottom quartile (16.3%). There was a higher proportion of medium fruit in top quartile yields (48.9% cf. 53.7%), but less large (18.4% cf. 29.9%). There were no significant differences in unmarketable yields or in fruit firmness, but there was a higher level of soluble solids in top quartile fruit (5.13% cf. 4.70%).

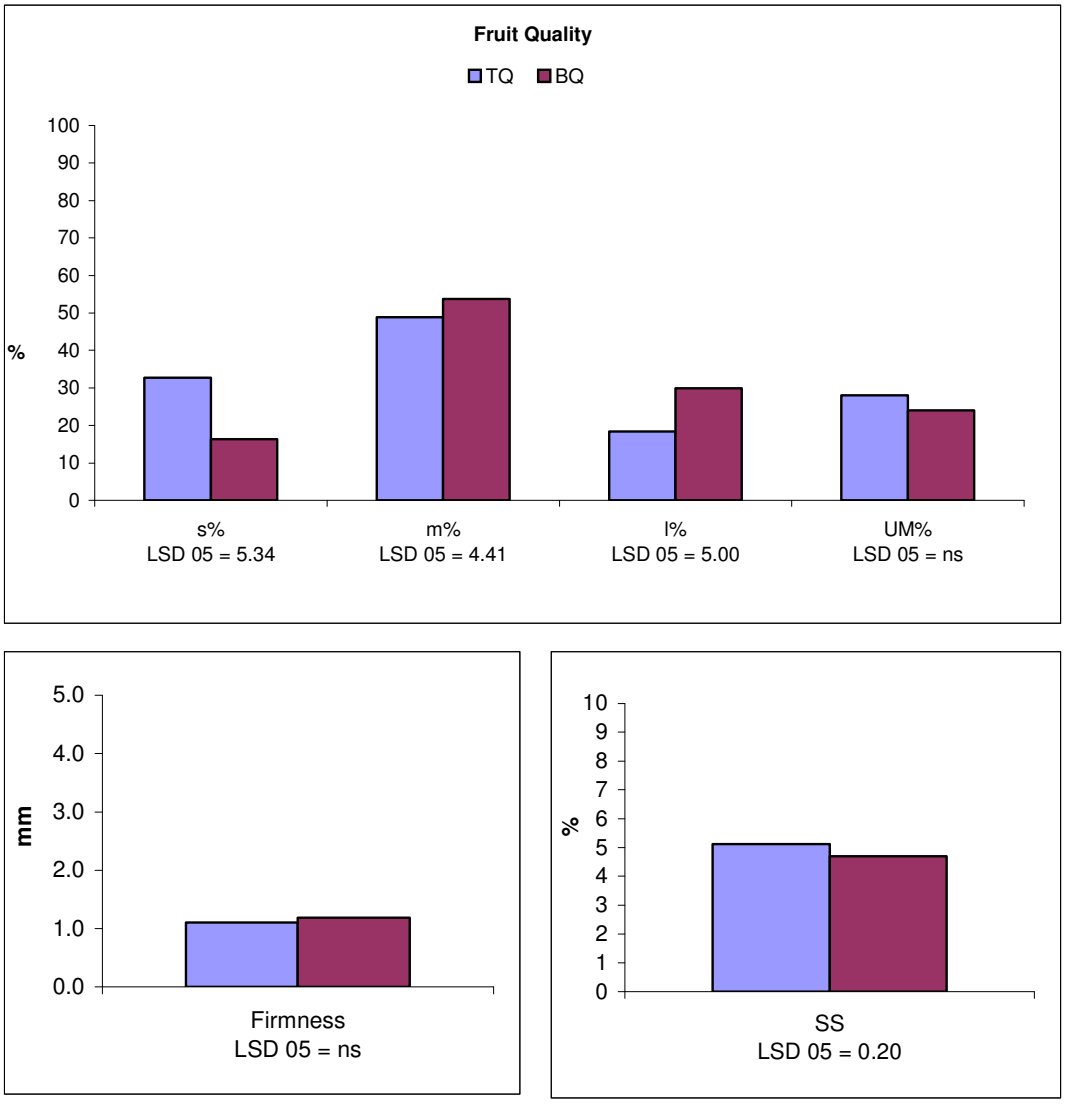


Figure 16 Fruit size components from the top (TQ) and bottom (BQ) yielding quartiles of commercial crops of the determinate tomato cv Rebel from the 2004/05 season in the Goulburn Valley. Small fruit are <60mm in diameter, medium 60-80mm, large >80mm. LSD = Least Significant Difference at 5%.

Figure 17 shows yield and fruit size results for indeterminate crops, averaged for each monitored season. Standard deviations (at the 95% confidence level) are shown to illustrate how widely values were dispersed from the seasonal means. On this basis, there is clear yield differentiation between the top and bottom yielding quartiles in all years except 2003/04. Fruit size differences are also clear for medium% in 2004/05 and for large% in 2001/02 and 2002/03.

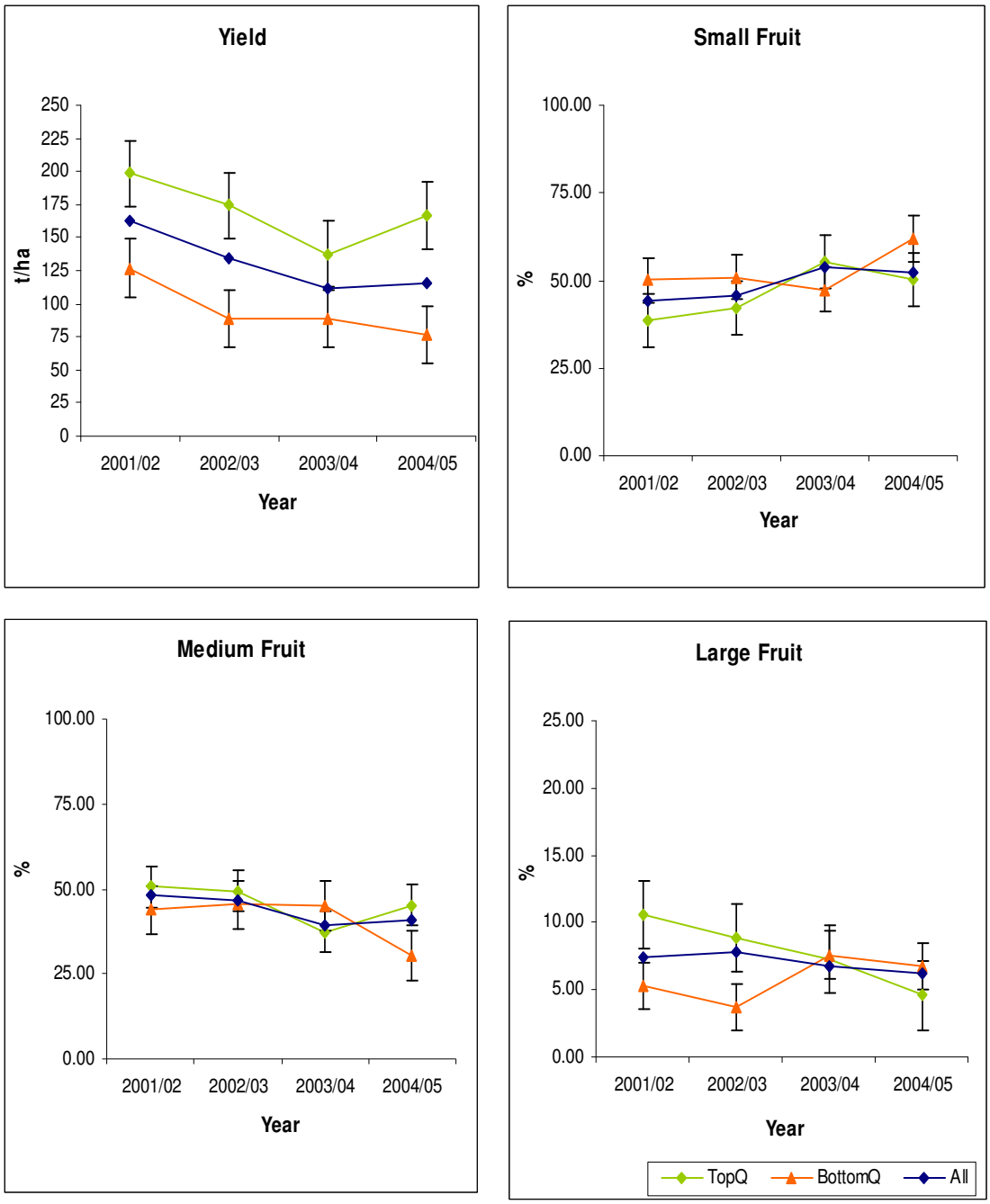


Figure 17 Average yield and fruit size components and the top and bottom quartile values from commercial crops of indeterminate tomato cv Red Ruby over four seasons (2001/02-2004/05) in the Goulburn Valley. Small fruit are <60mm in diameter, medium 60-80mm, large >80mm. Standard deviations are shown as error bars, and were determined at the 95% confidence level.

Effects of season, grower and site on nutrient levels, yield and fruit size

Indeterminate tomato crops

Table 13 shows the effects of grower, site and season over three years on nutrient levels, yield and fruit quality components averaged over the four growth stages. Grower management was related ($p<0.05$) to petiole phosphorus and magnesium. Significant impacts of season were found on phosphorus and calcium. There was a significant site impact only on calcium level. Grower/site interaction was also related to calcium, and grower/season interaction were a significant factor in P, Ca, Mg and Zn levels.

In terms of yield and fruit quality parameters, grower management was significantly related to total yield and large%. Season affects on fruit quality could not be estimated because the data set was too small.

Table 13 The significance of site and seasonal variables on petiole nutrient levels, yield and fruit quality components in commercial crops of indeterminate tomato cv Red Ruby monitored over three seasons (2001/02-2003/04) in the Goulburn Valley. Growers denoted as G1-G4.

	Nutrients (ppm)						Total			Fruit Quality		
	N	P	K	Ca	Mn	Zn	Yield t/ha	Small %	Medium %	Large %	Firmness mm	SS %
G1	4152	210	5334	963	482	2.88	135.20	50.80	38.70	10.55	1.11	4.37
G2	4529	142	4867	844	473	3.00	126.80	54.50	42.10	3.41	1.25	4.56
G3	4015	159	4852	831	535	2.75	131.70	49.20	44.10	6.73	1.24	4.61
G4	3721	180	4854	813	454	2.93	161.40	43.00	47.80	9.27	1.32	4.34
P values												
Grower	0.155	**0.003**	0.135	0.129	**0.040**	0.854	**0.022**	0.061	0.147	**<.001**	0.320	0.481
Season	0.074	**<.001**	0.119	**0.032**	0.073	0.146	-	-	-	-	-	-
Grower/Site	0.990	0.074	0.888	**0.036**	0.142	0.945	0.296	0.724	0.603	0.230	0.414	0.503
Grower/Season	0.397	**0.040**	0.608	**<.001**	**<.001**	**<.001**	-	-	-	-	-	-
Mean	4098	167	4926	849	487	2.89	139.30	49.20	43.80	7.05	1.24	4.48
Standard Deviation (95%)	335	30	238	68	35	0.11	15.47	4.79	3.80	3.15	0.09	0.13

Discussion

Crop performance

Yield varied widely between indeterminate crops, from 228 t/ha in 2001/2 to 66 t/ha in 2004/05 (Figure 3). This reflects differences in seasonal conditions and site management. The average yield from the sites monitored during seasons from 2001/2 – 2003/4 was 138.8 t/ha (S.D.±24.62). Over the four seasons described in this report, significant relationships were seen between petiole nutrient levels at the four monitored growth stages and total yield. While the limited data set means that many of these relationships must remain questionable, there were some consistent trends that are likely to be of more immediate value in fertigation management.

A significant negative relationship was evident between nitrogen and yield at the earlier stages of growth (Tables 5, 7 and 10). While yield generally increases with applied nitrogen, young plants need lower amounts of nutrients because their absolute growth rates (mg dry matter produced per unit time) are low (Singandhupe et al 2002). Excessive nitrogen at early flowering (stages 1-2) could have the effect of stimulating vegetative growth at the expense of fruit growth, thereby lowering yield. Similarly, petioles from the top yielding quartile had generally lower average nitrogen levels than the bottom quartile in indeterminate crops (Figures 9 and 10). In determinate crops, monitored only during the 2004/5 season (Figure 14), high nitrogen values were associated with lower yields from stages 2-4, with the opposite response at stage 1.

Excessive nitrogen can reduce phosphorus uptake (Gunes et al 1998, He et al 1999).

Relationships between petiole phosphorus levels and yield were not so clear. For indeterminate crops, Phosphorus was not significantly related to yield in the first three seasons (Table 5), but had a negative impact in later growth stages in 2004/5 (Table 7). Quartile contrasts on the other hand, showed that top crops were associated with higher P levels at growth stages 1-3 for the first three seasons (Figure 9), but not in 2004/5 (Figure 10). Phosphorus levels and profiles for the top quartile were similar in Figures 9 and 10, but P levels in the bottom quartile were much higher in 2004/5. This may suggest that phosphorus levels were sub-optimal in the first three years (Figure 9), although Table 5 does not support the contention. Yield of determinate crops was positively related to P at stages 1 and 4 (Table 10), and this is reflected in the quartile contrast (Figure 14), where P levels appear low at both stages, for BQ crops.

There was little significance in relationships between yield and the macronutrients potassium, calcium and magnesium in the first three seasons (Table 5, Figure 9). However, at the final (harvest) stage of indeterminate crops in 2004/5, yield was positively related to all three as well as sulfur, which was not measured in earlier seasons (Table 7). This affect is also seen in the quartile contrast (Figure 10), and may be a consequence of lower levels of these nutrients in the last season. If crops began to exhaust supply at the end of their growth, higher yields would be positively related to the levels of these elements. In determinate crops, relationships between yield and these nutrients were again most evident at stage 4, where they were less consistent than for indeterminate crops (Table 10).

Micronutrients were only monitored in season 2004/5, and interpretation is greatly limited by the size of the data set. Yield of indeterminate crops was negatively associated with manganese and zinc at stages 2 and 3, and with boron at stages 3 and 4 (Table 8, Figure 11). Determinate crops also showed mainly negative relationships between micronutrients and yield, particularly at stage 4 (Table 11), when levels of all these elements increased markedly (Figure 15). Copper levels at stages 2 and 3 were positively associated with higher yields in determinate crops (Table 4), possibly associated with the application of copper sprays for disease control.

Growers are keen to produce a high proportion of medium to large tomatoes. High nitrogen levels at the early monitored stages increased small fruit % and reduced medium fruit % (Tables 5 and 7, Figure 13) in trellis crops. Similarly, high N was associated with less medium% at stage 4 in all crops. This is presumably due to increased vegetative growth at the expense of fruit growth as suggested earlier.

Fruit size was also strongly related to Phosphorus. High petiole Phosphorus levels were associated with less mediums at all growth stages in the first three years for indeterminate crops (Table 5). Determinate crops produced a slightly different response, with P at all stages related to less large fruit, and at most stages more smalls (Table 7). Relationships between other macronutrients and fruit size were generally not significant or consistent, with the exception of potassium, which was positively associated with large% at stage 3.

While only measured over one season, micronutrients tended to have positive affects on fruit size (Tables 8 and 11). Indeterminate crops showed a positive relationship between all micronutrients and large% at stage 1, while copper and iron were associated with more large fruit at most growth stages. In determinate crops, boron, iron and particularly manganese were positively related to large%. Increases in large% were generally reflected in reduced small%.

Apart from nutrient levels, other possible factors affecting yield and fruit size are soil type, irrigation management, pruning, climatic conditions and pest control (Table 13).

Nutrient management

In order to more precisely forecast the fertiliser requirements for indeterminate and determinate tomato crops in northern Victoria, we estimated nutrient removal.

The potassium levels of soils used for processing tomato production were found to be non-limiting to yield by 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, or in gypsum to address soil structural issues. The routine recommendation for gypsum is 2.5 t/ha, which should easily replenish the 83 kg/ha reportedly removed by a fresh tomato crop (based on the figures of Huett and Dettman 1988).

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 (Locascio et al. 1997), where some nitrogen could be applied pre-planting. This practice could lead to high soil nitrogen levels however, and could impact on productivity, with our results suggesting that excess nitrogen during flowering leads to more small fruit. This can be addressed by reducing the amount of nitrogen applied pre planting and applying the nitrogen only when the plant requires it.

In practice, some of the trellis tomato growers participating in this study appeared to be applying higher rates of nitrogen than are necessary, at a stage where the plants are not able to utilise it. This increases the risk of leaching, and may impact on plant growth to reduce fruit size. 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.

The use of urea as a nitrogen source for fresh tomato crops in the Goulburn Valley is decreasing, but still makes up 19% of the total nitrogen applied. Nitrogen is applied mainly as calcium nitrate (32%) and potassium nitrate (49%), both of which are more expensive formulations (Ashburner and Top, 2003). Large amounts of calcium

are typically applied prior to planting in the form of lime and gypsum. With later applications of calcium through the drip system as well, a large reservoir of calcium builds up in the soil, the effects of which are not clear. Sap calcium was found to be negatively correlated with sap phosphorus (Ashburner and Top 2003) (supported by Figure 2), and sap phosphorus was also limiting yield. 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). This could be overcome by the application of higher rates of phosphorus – either broadcast or fertigated (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 Australian soils. Ammonium fertilisers should be used in moderation as ammonium toxicity occurs in tomatoes (Jones 1999).

Nutrient benchmarks

The benchmarks defined in this study were based on the top yielding quartile of the monitored crops. In any such analysis, the benchmarks are limited by the amount of data available. In the present study, crops were restricted to a single variety, and no low sap nitrogen crops were included, suggesting the need for further validation work. Various benchmark values have been published (Tables 14 and 15). Different methods of plant analysis have been used, but those of Hochmuth et al. (2004) were similar to those used in this study. In the case of petiole nitrogen, our top quartile figures were found to be higher than those defined for field tomatoes in Florida (Hochmuth et al. 2004). While figures for potassium were very similar at the first flower stage, we found a subsequent rise with growth stages, whereas the Florida study recommended that levels should diminish. This is likely to be a consequence of different climate, soil and management systems.

Table 14 A summary of benchmarking of sufficient macronutrient concentrations for tomato plants from different studies.

		This Study		Reuter & Robinson	Hochmuth et al.		UC Davis	Rosen & Eliason	Campbell
		Trellis	Ground	Field	Greenhouse	Field	Field	Field	Trellis
	Stage of	Fresh petiole	Fresh petiole	Dried petiole	Fresh petiole	Fresh petiole	Fresh petiole	Dried petiole	Dried petiole
Nutrients	Growth	Ppm	ppm	%	ppm	ppm	ppm	%	%
N	1-2 Flower	5350-6750	7290	5.5-6.0	4420-5300	4420-5300	3092-3978	-	3.5-5.0
	3-4 Flower	4234-5104	4228	-	3536-4420	2652-3536	2652-3536	-	3.5-5.0
	5-6 Flower	3226-3588	1982	3.1-3.95	3536-4420	1768-2652	2210-3094	4.0-6.0	3.5-5.0
	2-3 Harvest	1706-3210	786	2.2-2.5	3094-3978	1320-1768	1768-2652	-	3.5-5.0
P	1-2 Flower	165-347	278	0.75-0.85	-	-	-	-	0.3-0.7
	3-4 Flower	132-282	167	-	-	-	-	-	0.3-0.7
	5-6 Flower	95-215	120	0.4-0.6	-	-	-	0.25-0.80	0.3-0.7
	2-3 Harvest	59-149	105	0.4<	-	-	-	-	0.3-0.7
K	1-2 Flower	3710-4474	4615	3.0-5.0	4500-5000	3500-4000	-	-	3.0-4.5
	3-4 Flower	3978-5072	4296	-	4000-5000	3000-3500	-	-	3.0-4.5
	5-6 Flower	4202-5586	4022	3.0-5.0	4000-5000	3000-3500	-	2.9-5.0	3.0-4.5
	2-3 Harvest	4402-6122	3174	5.2<	3500-4000	2000-2500	-	-	3.0-4.5
Ca	1-2 Flower	571-871	345	1.5-2.5	-	-	-	-	1.0-2.0
	3-4 Flower	590-908	297	-	-	-	-	-	1.0-2.0
	5-6 Flower	620-942	331	1.4-4.0	-	-	-	1.0-3.0	1.0-2.0
	2-3 Harvest	647-965	668	4.0-4.3	-	-	-	-	1.0-2.0
Mg	1-2 Flower	310-506	525	0.4-0.6	-	-	-	-	0.3-0.8
	3-4 Flower	429-497	591	-	-	-	-	-	0.3-0.8
	5-6 Flower	399-519	667	0.4-0.9	-	-	-	0.4-0.6	0.3-0.8
	2-3 Harvest	453-583	1856	1.1-1.2	-	-	-	-	0.3-0.8
S	1-2 Flower	136.30	178.20	-	-	-	-	-	0.2-0.8
	3-4 Flower	227.30	223.40	-	-	-	-	-	0.2-0.8
	5-6 Flower	246.20	223.20	-	-	-	-	0.4-1.2	0.2-0.8
	2-3 Harvest	334.90	515.80	0.08<	-	-	-	-	0.2-0.8

Table 15 A summary of benchmarking of sufficient micronutrient concentrations for tomato plants from different studies.

	Stage	This Study		Reuter & Robinson	Rosen & Eliason	Campbell
	Of	Trellis Fresh petiole	Ground Fresh petiole	Field Dried petiole	Field Dried petiole	Trellis Dried petiole
Nutrients	**Growth**	**ppm**	**Ppm**	**mg/kg**	**ppm**	**ppm**
B	1-2 Flower	0.35	0.38	40-100	-	30-75
	3-4 Flower	0.59	0.73	-	-	30-75
	5-6 Flower	0.23	0.40	30-100	25-60	30-75
	2-3 Harvest	0.60	0.88	-	-	30-75
Cu	1-2 Flower	1.48	2.30	5-10	-	5-30
	3-4 Flower	3.80	8.00	-	-	5-30
	5-6 Flower	2.50	5.81	5-10	5-20	5-30
	2-3 Harvest	2.77	2.54	-	-	5-30
Fe	1-2 Flower	1.06	0.97	100-300	-	45-300
	3-4 Flower	1.27	1.47	-	-	45-300
	5-6 Flower	2.12	1.92	100-300	40-200	45-300
	2-3 Harvest	2.66	2.42	-	-	45-300
Mn	1-2 Flower	1.06	2.57	50-500	-	30-300
	3-4 Flower	1.27	2.95	-	-	30-300
	5-6 Flower	2.12	4.52	50-100	40-250	30-300
	2-3 Harvest	2.66	16.90	-	-	30-300
Zn	1-2 Flower	1.13	2.16	-	-	18-75
	3-4 Flower	0.80	2.82	30-200	-	18-75
	5-6 Flower	0.99	3.34	24.6	20-50	18-75
	2-3 Harvest	0.98	9.96	-	-	18-75

Section 2 – Nutrient Removal and Uptake

Introduction

The amount of nutrients accumulated by a plant during its growth, including those removed during harvest, is often used as a guide to fertiliser application rates. Plants vary widely in both chemical content and yield, so it follows that they will also vary in their uptake of nutrients from the soil (Glendinning 1990).

Generally, the size of the crop is the dominant influence, but several other factors such as variety, soil type, soil fertility and seasonal conditions affect the rate and amount of nutrient uptake by crop plants. Consequently, it is not possible to estimate the exact amount of nutrients a specific crop will remove from the soil.

This study was undertaken to quantify the amount of nutrients taken up by tomato plants during their growth, to be used as a guide to fertiliser requirements.

Methods

Experimental sites: Data were gathered in the 2003/4 season, from a total of eight sites, four ground and four trellis, incorporating the management practices of eight growers. Within each trellis site a 10 m X 4.5 m plot over three rows was used as the source of plant samples for dry matter analysis. Harvests were conducted from sub-plots 2m long at four growth stages (Stage 1 =1^{st} - 2^{nd} flower, Stage 2 = 3^{rd} - 4^{th} flower, Stage 3 = 5^{th} – 6^{th} flower and Stage 4 = 2^{nd} - 3^{rd} harvest) to estimate yield and fruit size components. In determinate tomato crops, only one plant sample was taken at 2-3 harvest from 2 m sub-plots at each site for yield and fruit quality estimation. Sampled plants were partitioned into 4-5 different plant parts (roots, stems, leaves, shoots (young stems which are growing below flower truss and must be pruned to allow plants grow vertically) and fruit (all harvested fruit), according to the crop type and growth stage. These samples were dried in hot air oven at 60^{o}C, ground and sent to the State Chemical Laboratory for analysis of N, P, K, Ca, Mg, Zn, Na, B, S, Cu, Fe and Mn.

Yield and fruit size analysis: Yield and fruit size were estimated from weekly harvests of ripe fruit, which were graded into small (< 60 mm), medium (60 – 80 mm) and large (> 80 mm) size categories and then weighed.

Statistical analysis and development of benchmarks: The amount of nutrient taken by each plant component was calculated, with variability expressed as standard deviations (S.D.) with 95% confidence intervals. The relationships between nutrient levels and plant proportions (% root, stem, leaf, fruit and shoot) were calculated using linear regression techniques.

Results

Nutrient Uptake

Indeterminate tomatoes
The four indeterminate (trellis) tomato crops studied produced an average yield of 108 tonnes, and removed 204 kg nitrogen (S.D. ±62.8), 22 kg phosphorus (S.D.±8.2), 255 kg potassium (S.D.±71.5) and 216 kg calcium (S.D.±48.4) per hectare. The uptake of trace elements was generally much lower, as expected, with highest values for sodium and iron (Figure 18).

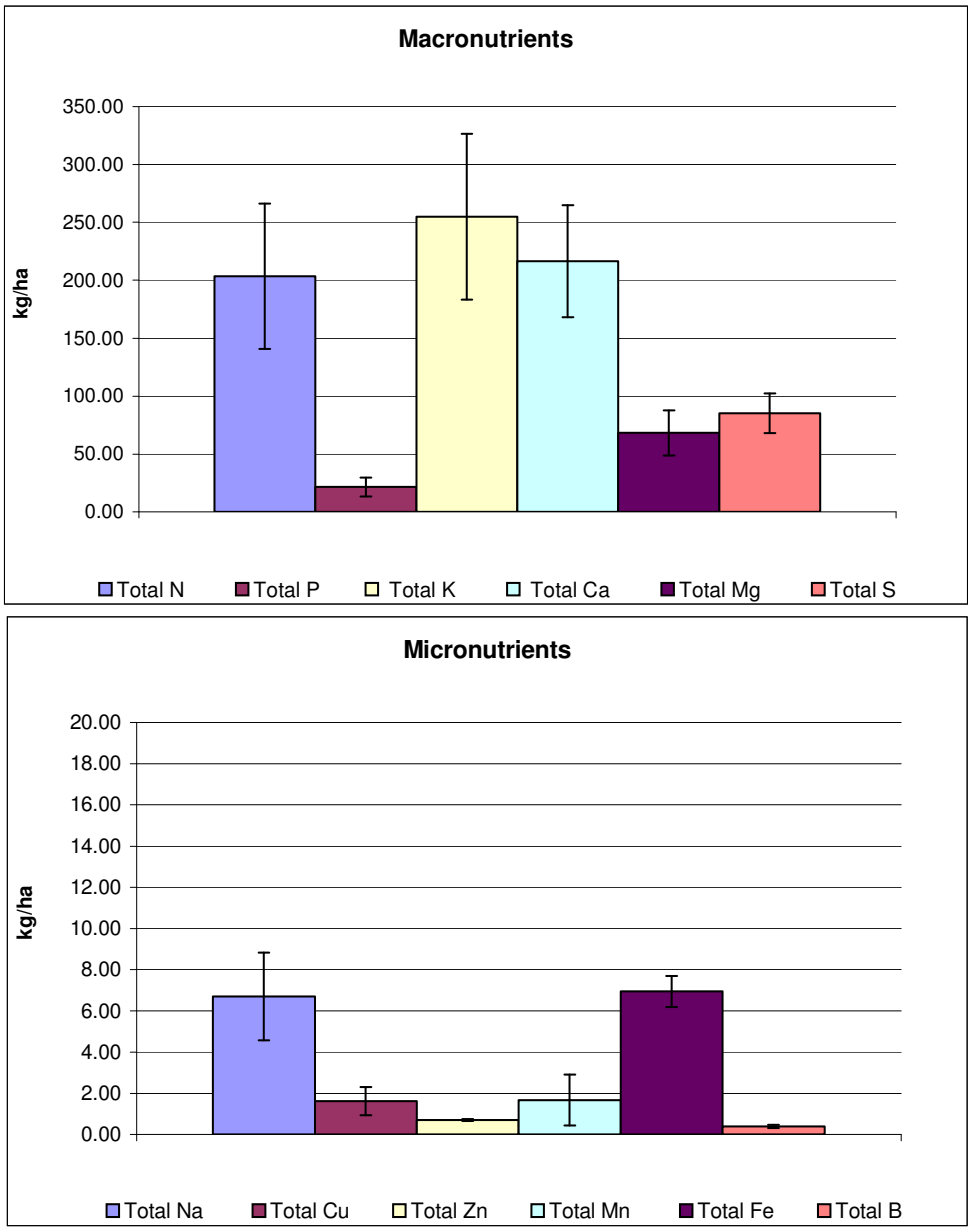
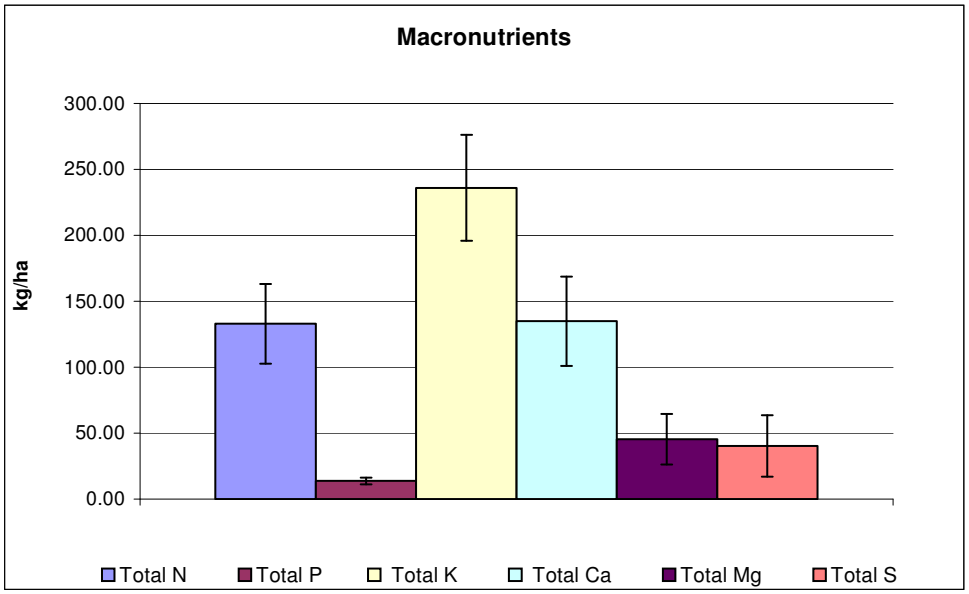


Figure 18 The amount of macro and micro nutrients taken up by commercial crops of indeterminate tomato cv Red Ruby during the 2003/04 season in the Goulburn Valley. Standard deviation values are expressed in terms of 95% confidence intervals.

Determinate tomatoes

Ground tomato crops yielding an average of 130 t/ha removed 133kg nitrogen (S.D.±30.1), 14 kg phosphorus (S.D.±2.5), 236 kg potassium (S.D.±40.1) and 135 kg calcium (S.D.±34.0) (Figure 19). Trace element results showed sodium and iron to be highest.



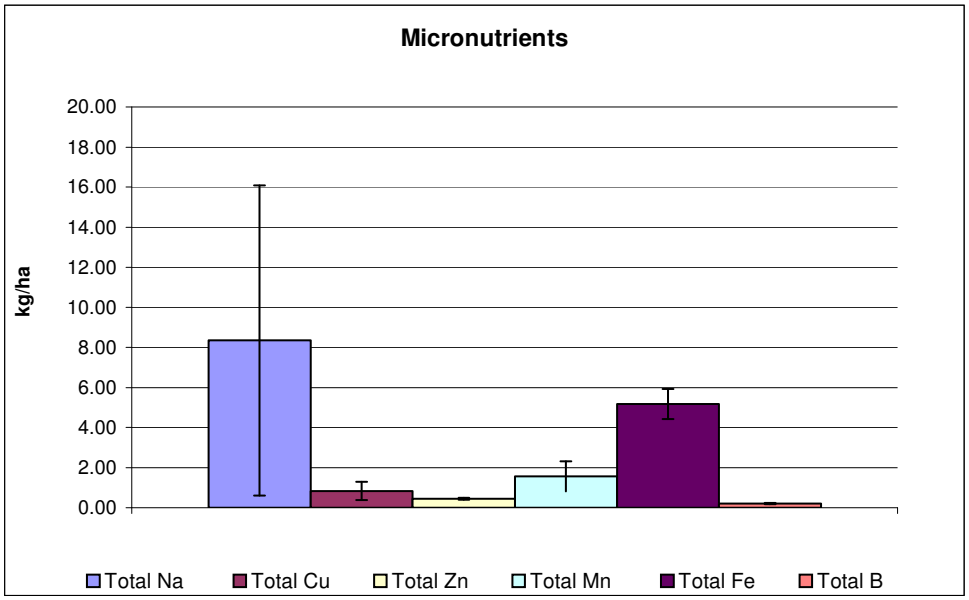


Figure 19 The amount of macro and micronutrients taken up by commercial crops of determinate tomato cv Rebel during the 2003/04 season in the Goulburn Valley. Standard deviation values are expressed in terms of 95% confidence intervals.

Expressed another way, the production of one tonne of fresh trellis tomatoes required the plants to absorb 1.88 kg nitrogen, 0.20 kg phosphorus, 2.36 kg potassium and 2 kg calcium. Using this approach, Table 16 shows the amount of nutrients to produce one tonne of fresh fruit for ground and trellis crops.

Table 16 The amount of nutrients removed by commercial crops of determinate and indeterminate tomato cultivars Rebel and Red Ruby per tonne of total average yield in 2003/04 in the Goulburn Valley.

Nutrients	Determinate Crop/Ground Kg/ha	Indeterminate Crop/Trellis kg/ha
Macronutrients		
Nitrogen (N)	1.02	1.88
Phosphorus (P)	0.11	0.20
Potassium (K)	1.82	2.36
Calcium (ca)	1.04	2.00
Magnesium (Mg)	0.35	0.63
Sulfur (S)	0.31	0.79
Micronutrients		
Sodium (Na)	0.0642	0.0569
Copper (Cu)	0.0064	0.0150
Zinc (Zn)	0.0034	0.0065
Manganese (Mn)	0.0120	0.0155
Iron (Fe)	0.0398	0.0643
Boron (B)	0.0016	0.0036

Partitioning of nutrient uptake

Indeterminate tomatoes

Nutrients were partitioned into the various plant components (Table 17), with leaves being the major recipient of nitrogen, calcium, magnesium and sulfur at all growth stages. The exception was potassium, where highest amounts were found in the stems.

Table 17 Cumulative removal of macronutrients (kg/ha) by components of trellis tomato plants from commercial crops of indeterminate cv Red Ruby during the 2003/04 season in the Goulburn Valley. Standard Deviation values are expressed in terms of 95% confidence intervals.

Nutrients	**Amount of nutrient removed by plant parts kg/ha**					**Total Nutrient removed**
Growth Stage	**Root**	**Stem**	**Leaf**	**Fruit**	**Shoot**	**Kg/ha**
N						
Stage 1	1.4	7.1	14.3			22.8
Stage 2	2.7	17.8	26.3	3.3		49.4
Stage 3	1.9	26.8	37.8	15.1		81.6
Stage 4	$5.5_{\pm 1.3}$	$56.8_{\pm 14.4}$	$90.2_{\pm 19.9}$	$45.6_{\pm 5.7}$	$5.6_{\pm 1.0}$	203.5
% of total uptake	*2.7*	*27.9*	*44.3*	*22.4*	*2.7*	
P						
Stage 1	0.2	1.1	1.7			3.0
Stage 2	0.2	2.7	2.3	0.6		5.9
Stage 3	0.2	4.6	3.3	2.6		10.7
Stage 4	$0.6_{\pm 0.1}$	$5.2_{\pm 1.4}$	$8.5_{\pm 2.1}$	$6.5_{\pm 1.2}$	$0.65_{\pm 0.1}$	21.5
% of total uptake	*2.7*	*24.5*	*39.7*	*30.2*	*3.0*	
K						
Stage 1	1.8	12.0	8.4			22.2
Stage 2	2.5	30.6	17.7	4.3		55.0
Stage 3	2.4	50.5	24.3	22.3		99.4
Stage 4	$5.5_{\pm 1.1}$	$106.9_{\pm 17.6}$	$72.4_{\pm 12.3}$	$65.35_{\pm 11.5}$	$4.74_{\pm 0.8}$	254.8
% of total uptake	*2.2*	*41.9*	*28.4*	*25.6*	*1.9*	
Ca						
Stage 1	0.6	2.8	10.1			13.4
Stage 2	0.9	8.9	26.3	0.4		36.5
Stage 3	1.1	18.5	42.6	1.5		63.7
Stage 4	$3.3_{\pm 0.5}$	$44.5_{\pm 7.7}$	$162.1_{\pm 22.2}$	$4.6_{\pm 1.1}$	$2.0_{\pm 0.4}$	216.4
% of total uptake	*1.5*	*20.6*	*74.9*	*2.1*	*0.9*	
Mg						
Stage 1	0.3	1.1	1.9			3.2
Stage 2	0.4	3.4	4.6	0.2		8.6
Stage 3	0.3	8.9	9.7	1.2		20.1
Stage 4	$1.3_{\pm 0.5}$	$21.3_{\pm 3.9}$	$41.43_{\pm 7.2}$	$3.6_{\pm 0.6}$	$0.66_{\pm 0.1}$	68.3
% of total uptake	*1.9*	*31.2*	*60.6*	*5.3*	*1.0*	
S						
Stage 1	0.2	0.6	3.76			4.6
Stage 2	0.3	2.3	10.35	0.3		13.3
Stage 3	0.3	5.4	16.18	1.4		23.3
Stage 4	$0.7_{\pm 0.1}$	$12.4_{\pm 2.1}$	$67.10_{\pm 7.3}$	$4.1_{\pm 0.6}$	$0.9_{\pm 0.1}$	85.2
% in total uptake	*1.3*	*14.5*	*78.7*	*4.8*	*1.1*	

Nutrient removal can also be calculated on the basis of growth stage (Figure 20).

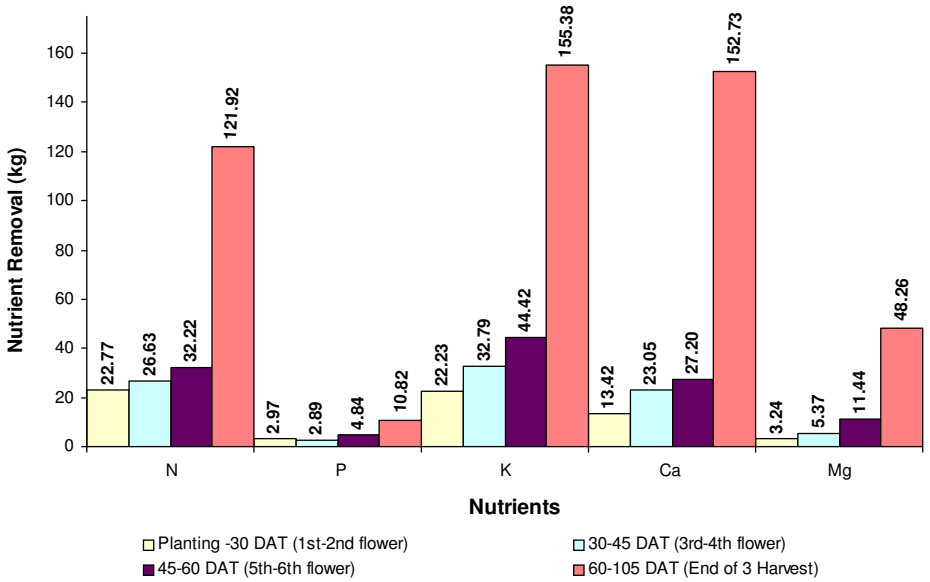


Figure 20 Estimated removal of nutrients by commercial crops of indeterminate tomato cv Red Ruby during 2003/04 season in the Goulburn Valley.

Most trace elements removed by trellis tomato crops were found in the leaves (Table 18), although stem tissues contained the highest proportion of zinc (S.D.±27.0). The amount of iron detected in the roots was also quite high (2191.8 g/ha).

Table 18 Trace element removal and partitioning into plant components by commercial crops of indeterminate tomato cv Red Ruby during the 2003/04 season in the Goulburn Valley.

	Amount of nutrient removed by plant parts g/ha					
	Na	**Cu**	**Zn**	**Mn**	**Fe**	**B**
Root	$210.0_{\pm 50.0}$	$43.4_{\pm 29.2}$	$50.2_{\pm 9.2}$	$68.4_{\pm 37.3}$	$2191.8_{\pm 1064.8}$	$4.4_{\pm 0.7}$
Stem	$3120.0_{\pm 600.0}$	$163.6_{\pm 48.1}$	$403.3_{\pm 27.0}$	$268.8_{\pm 64.0}$	$642.0_{\pm 191.8}$	$66.9_{\pm 12.0}$
Leaf	$2630.0_{\pm 470.0}$	$1349.4_{\pm 296.3}$	$198.0._{\pm 11.3}$	$1282.5_{\pm 516.4}$	$3855.6_{\pm 844.2}$	$295.0_{\pm 35.3}$
Fruit	$700.0_{\pm 150.0}$	$40.9_{\pm 9.2}$	$44.1_{\pm 7.0}$	$42.3_{\pm 11.2}$	$220.9_{\pm 66.4}$	$17.7_{\pm 7.0}$
Shoot	$50.0_{\pm 9.0}$	$23.5_{\pm 13.7}$	$6.7_{\pm 2.4}$	$9.9_{\pm 7.0}$	$30.8_{\pm 13.5}$	$4.2_{\pm 1.4}$
Total	6071.0	1620.8	702.2	1671.8	6941.1	388.2

Determinate tomatoes

Stems contained the highest proportion of nitrogen, potassium and magnesium, while the leaf contained the highest proportion of sulfur in ground tomato crops. The amount of phosphorus recovered was highest in fruit, whereas calcium distribution was almost equal between stem and leaf components. (Tables 19).

Table 19 Removal of macronutrients by commercial crops of determinate tomato cv Rebel (and % of total uptake at harvest stage) during the 2003/04 season in the Goulburn Valley.

Nutrients	Amount of nutrient removed by plant parts kg/ha				Total Nutrient removed
	Root	Stem	Leaf	Fruit	kg/ha
N	$4.1_{\pm.52}$	$55.5_{\pm6.54}$	$27.8_{\pm5.6}$	$45.5_{\pm4.6}$	132.9
% of total uptake	*3.1*	*41.8*	*20.9*	*34.2*	
P	$0.4_{\pm0.1}$	$5.0_{\pm0.7}$	$2.4_{\pm0.5}$	$6.0_{\pm.12}$	13.7
% of total uptake	*2.6*	*36.2*	*17.2*	*44.0*	
K	$5.5_{\pm0.7}$	$127.5_{\pm17.4}$	$33.8_{\pm2.9}$	$69.3_{\pm3.3}$	236.0
% of total uptake	*2.3*	*54.0*	*14.3*	*29.4*	
Ca	$4.0_{\pm0.6}$	$63.1_{\pm0.5}$	$63.0_{\pm10.5}$	$4.7_{\pm0.8}$	134.8
% of total uptake	*3.0*	*46.8*	*46.7*	*3.5*	
Mg	$1.0_{\pm0.2}$	$29.3_{\pm7.6}$	$11.5_{\pm2.6}$	$3.6_{\pm0.21}$	45.4
% of total uptake	*2.1*	*64.6*	*25.3*	*8.0*	
S	$0.6_{\pm0.1}$	$10.9_{\pm1.8}$	$25.2_{\pm9.9}$	$3.7_{\pm0.2}$	40.3
% of total uptake	*1.5*	*27.0*	*62.4*	*9.1*	

In determinate crops, micronutrients were partitioned strongly into the leaves, with highest proportions of copper, manganese, iron and boron (Table 20). The stems contained the highest proportion of sodium and zinc, and once again the roots were a significant destination for iron.

Table 20 Micronutrient uptake by determinate tomato cv Rebel (and % in total uptake at harvest stage) in the 2003/04 season.

	Amount of nutrient removed by plant parts g/ha					
Plant Parts	**Na**	**Cu**	**Zn**	**Mn**	**Fe**	**B**
Root	$380.0_{\pm110.0}$	$15.0_{\pm4.4}$	$34.4_{\pm8.4}$	$137.5_{\pm93.5}$	$1303.8_{\pm507.0}$	$5.4_{\pm1.6}$
Stem	$5670.0_{\pm2930.0}$	$176.8_{\pm32.7}$	$334.3_{\pm16.3}$	$598.4_{\pm333.9}$	$922.5_{\pm161.5}$	$77.9_{\pm6.5}$
Leaf	$1400.0_{\pm600.0}$	$708.7_{\pm204.8}$	$37.5_{\pm1.7}$	$771.0_{\pm390.0}$	$2629.0_{\pm247.0}$	$94.7_{\pm9.1}$
Fruit	$900.0_{\pm300.0}$	$33.4_{\pm4.3}$	$37.3_{\pm4.4}$	$50.9_{\pm16.7}$	$318.2_{\pm148.9}$	$26.3_{\pm1.8}$
Total	8350.0	935.9	443.5	1557.8	5773.5	204.1

Growth and nutrient uptake

Indeterminate tomatoes

Nitrogen uptake during the initial 30 days after transplanting (DAT) was 11.2% of the total nitrogen taken by the crops by the end of the third harvest. Later, nitrogen uptake slightly increases depending on the age of plants (Table 18). The proportion of nitrogen and other macronutrients distributed in plant parts dramatically increased between 60 and 105 DAT (Figure 20). During the period from about 15 weeks after transplanting to the third harvest, 59.9% of nitrogen, 50.3% of phosphorus and

61.0% of potassium were taken up by plants. Thus, about half of the total nutrient uptake takes place between 60 and 105 DAT, a period coinciding with peak fruit development (Table 21).

Table 21 Nutrient accumulation (%) from transplanting to harvest in commercial crops of indeterminate tomato cv Red Ruby during the 2003/04 season in the Goulburn Valley.

DAT	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
Planting - 30 DAT	11.2	13.8	8.7	6.2	4.7	5.4
30 – 45	13.1	13.4	12.9	10.6	7.9	10.2
45 - 60	15.8	22.5	17.4	12.6	16.7	11.7
60 – 100	59.9	50.3	61.0	70.6	70.6	72.7

DAT: Days After Transplanting

This result demonstrates the need for nutrient application and monitoring throughout the growth cycle of indeterminate plants if crop productivity is to be maximised. The period when plants have the greatest requirement for potassium, nitrogen, calcium and phosphorus is during fruit-fill. Nutrients are also taken up rapidly when plants are young, but the rate of uptake falls when the plant is approaching maturity (Figure 21).

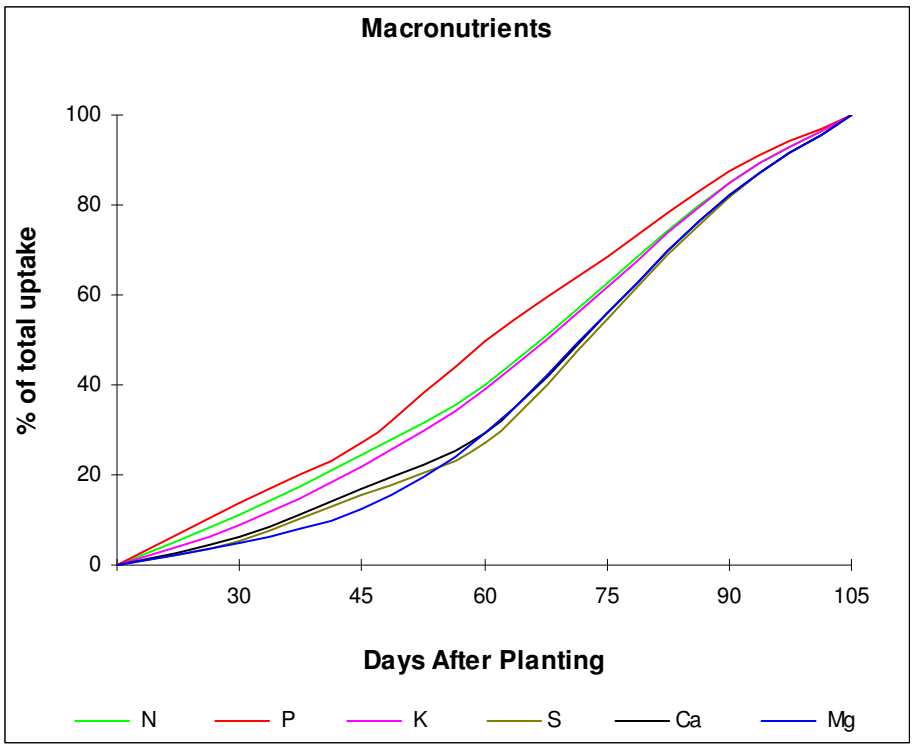


Figure 21 Uptake of macronutrients by commercial crops of indeterminate tomato cv Red Ruby from the 2003/04 season in the Goulburn Valley.

Micronutrient uptake followed a similar curve to that of macronutrients. Over the half of micronutrient uptake occurred during the last 45 days when fruit growth is high. (Figure 22).

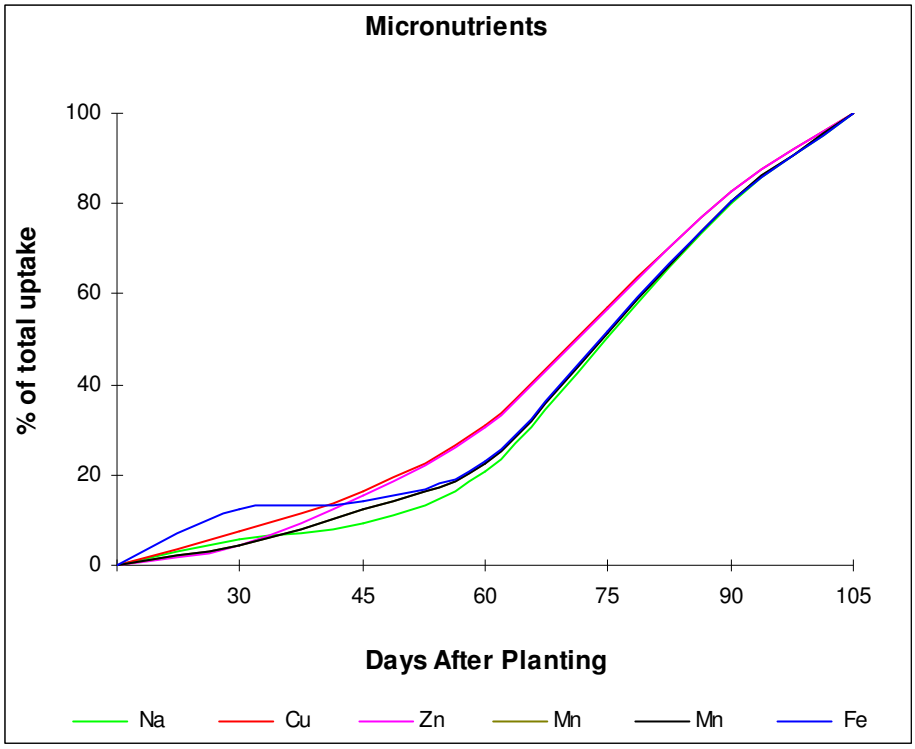


Figure 22 Micronutrient uptake by commercial crops of indeterminate tomato cv Red Ruby from the 2003/04 season in the Goulburn Valley.

Discussion

Indeterminate tomato crops with an average yield of 108 tonnes removed 204 kg nitrogen, 22 kg phosphorus, 255 kg potassium and 216 kg calcium per hectare. Leaves contained the highest proportion of total nitrogen (44.3%), phosphorus (39.7%), calcium (74.9%), magnesium (41.4%) and sulfur (78.7%) absorbed by the plant. Similarly, a determinate crop yielding an average of 130 t/ha removed 133 kg nitrogen, 14 kg phosphorus, 236 kg potassium and 135 kg calcium per hectare. In the determinate crop, the highest percentage of nitrogen, potassium and magnesium removed were found in the stems, while the highest amount of phosphorus was in fruit. Calcium was contained equally in stems and leaves.

Plants vary widely in both chemical composition and yield. It follows that they also vary in their uptake and removal of nutrients from the soil. Like other *solanaceous* vegetables (eggplant, chilli and bell peppers), tomatoes generally take up large amounts of nutrients (Hegde 1997). Jaime et al (1987) observed that 180 kg N/ha applied through drip irrigation, could produce a tomato yield of 16.8 kg/plant. The production context (eg field or glasshouse) was not specified in this report, but by comparison, we measured higher nitrogen removal (204 kg N/ha) with a lower yield (4.9 kg/plant assuming a planting density of 22,000 plants/ha). The quantity of

nutrients to be applied depends on the yield potential of the cultivar, the level of available nutrients in the soil, and growing conditions (Hegde 1997). Because the plants need nutrients even up to fruit ripening, application methods such as fertigation, split application of fertilisers, use of slow release nitrogen fertiliser, and integrated use of fertilisers and organic sources of nutrients have proved very effective in increasing nutrient use efficiency and crop productivity. For example, an application of 505 kg/ha of total NPK through drip irrigation resulted in a higher nutrient uptake in tomato than when the same NPK rate was applied before planting (Dangler and Locascio 1990). Srinivas (1990) studied NPK uptake in tomatoes on soils with different levels of N application, and found that nutrient uptake declines with increasing soil moisture stress, and increases with higher levels of N application.

In trellis tomatoes, maximum uptake rates for nutrients appear to be from 60-80 days after transplanting (Figures 20 and 21), which would coincide with the initiation of ripening of the first fruit. This is also the time of maximum growth (Penelosa et al, 1988). Fertiliser requirement depends on the yield potential of the cultivar, the level of available plant nutrients already in the soil, and growth conditions (Hegde 1997). Nutrient management practices should be aimed at supplying just enough fertiliser to meet the crop's demands with minimal wastage (ie optimising nutrient use efficiency). Such practices will be environmentally friendly, and lead to sustainability in vegetable production.

Maximum growth rates in trellis tomatoes, when plants have the greatest requirement for all major nutrients, occur just before the fruit begin to ripen (Penelosa et al, 1988). In this study, over half the uptake of nutrients occurred during the last 60 days when fruit growth is at its peak (Figures 18 and 19). This demonstrates the need for nutrient application and monitoring throughout the growth cycle of indeterminate plants if crop productivity is to be maximised. Growth may then slow, and as the crop matures there may even be a slight decline in dry matter, due to leaf fall (Hegde 1997).

The results suggest that trellis tomato growers in the Goulburn Valley apply more fertiliser than ground growers for less average yield, although the average yield obtained in our trials (108 t/ha) was lower than would normally be expected from commercial trellis crops.

Section 3 - Amelioration of P fixation

Introduction

The availability of phosphorus limits plant growth in many soils, especially the acid soils of the humid tropical lowlands (Lehmann et al 2001). At the same time, global resources for the production of P fertilisers are declining, and may even be exhausted within about 100 years if current growth in usage continues (Stevenson and Cole, 1999). Sound management strategies are needed to utilise applied and native soil Phosphorus more effectively, thus reducing the need for fertiliser application.

Australian soils are characteristically low in natural phosphorus with the exception of a few soils of basaltic origin. Due to cropping and the depletion of phosphorus resources, even soils with a high natural level reach the stage when phosphorus fertiliser is necessary to maintain or increase crop yields (Glendinning 1990). Phosphorus is most readily available in neutral to slightly acid soils. It becomes fixed as calcium compounds and in acid soils, as compounds of iron and aluminium. High rates of lime and fertiliser-P are characteristically required to obtain high crop yields on highly acid soils. The low P status of highly acid soils is a particular problem because large amounts of P need to be applied in order to raise concentrations of available soil P to an adequate level (Lehmann et al 2001). This is because such soils contain large quantities of aluminium and iron hydrous oxides, which have the ability to adsorb P onto their surfaces. Thus, much of the added P is 'fixed' and is not readily available for crop use.

The objective of this study was to evaluate the effect of various fertiliser mixes that are likely to be used in fresh tomato production, on crop performance and Phosphorus availability.

Methods

The field study to evaluate strategies relating to problems of phosphorus fixation was conducted in 2002/03 on a trellis tomato crop at the DPI Tatura Centre. Single row plots (10m long) were replicated 4 times in a randomised block design, and results were subjected to analysis of variance procedures. Treatments consisted of four different nitrogen fertiliser mixes:

1- $CaNO_3$ + KNO_3,

2- Urea + KNO_3,

3- $CaNO_3$ + KNO_3 + urea phosphate and

4- Urea + KNO_3 + urea phosphate.

The rates of fertilisers (Appendix 1) applied were calculated on the basis of current commercial practice. Fertilisers were applied weekly with a single fertigation pump, through separate buried drip irrigation lines to each treatment. Plant petiole samples were taken twice; at second flower and second harvest, and were analysed for N, P, K, Ca, Mg and Zn. Fruit were harvested 6 times for yield and quality measurements along with petiole sap levels. Average petiole sap nutrient levels were calculated and variability expressed as standard deviations with 95% confidence intervals.

Results

Yield and fruit size components were measured (Table 22), and no significant differences ($p<0.05$) were found between the treatments.

Table 22 Yield and fruit size produced under different fertiliser treatments in indeterminate tomato cv Red Ruby in 2002/03 season.

		Fruit quality				
	Total Yield	Small	Medium	Large	Firmness	SS
Treatments	t/ha	%	%	%	Mm	%
1	162.50	42.50	52.10	5.40	1.63	5.15
2	151.40	49.10	47.60	3.28	2.33	5.25
3	140.40	47.00	48.30	4.74	1.61	5.25
4	154.90	46.10	48.30	5.60	1.47	5.57
LSD (0.05)	*33.19*	*9.00*	*8.24*	*3.30*	*0.86*	*0.43*
Mean	152.30	46.20	49.10	4.75	1.76	5.31

Petiole sap samples were also taken at second flower and harvest stages, and several significant ($p<0.05$) differences in nutrient levels were found between treatments. Phosphorus levels were lower in treatment 1 than in 2 and 3 at the second flower stage, but there were no significant differences at harvest. Most other differences also involved treatment 1 at the first sampling stage (second flower), when magnesium and zinc levels were lower, but potassium was higher than in some of the other treatments (Table 23). The only significant difference at the second sampling stage (Harvest) was between treatment 2 and treatment 4 for zinc.

Table 23 Sap nutrient levels at two growth stages (second flower – SF and harvest – H) in indeterminate tomato cv Red Ruby during the 2002/03 season.

	N		P		K		Ca		Mg		Zn	
Treatment	SF	H	SF	H	SF	H	SF	H	SF	H	SF	H
1	5965.0	2364.0	91.2	68.5	6045.0	5898.0	454.0	706.5	602.0	698.0	2.01	3.12
2	6088.0	2395.0	110.8	64.2	5342.0	5953.0	430.0	709.8	616.0	698.0	2.94	3.06
3	6335.0	2399.0	111.8	64.2	5572.0	5669.0	446.0	686.8	723.0	687.2	2.84	3.13
4	6568.0	2492.0	110.2	60.5	5798.0	5814.0	508.0	710.8	697.0	715.8	2.72	3.19
Mean	**6239.0**	**2412.5**	**106.0**	**64.4**	**5689.0**	**5883.6**	**459.0**	**703.4**	**660.0**	**699.8**	**2.63**	**3.13**
LSD (0.05)	*624.3*	*238.3*	*19.4*	*9.0*	*516.6*	*378.4*	*122.8*	*64.0*	*66.1*	*40.4*	*0.66*	*0.08*

Discussion

The results of this experiment did not reveal significant relationships between nutrient application strategies, crop productivity and P utilisation. Varying the form of N applied, or supplementing the fertigation mix with P had no significant ($p<0.05$) effect on the yield or quality parameters measured in a trellis tomato crop. Petiole sap measurements at second flower showed that P levels were lower in the first treatment, but this result was not repeated at harvest, and was not reflected in yield or fruit quality. Treatment 1 included the application of calcium, which can reduce available P. No such affect was evident in treatment 3, which also contained Ca, but with additional P.

It should be noted that this experiment was conducted over a single season only, and significant changes to soil characteristics such as pH (acidification) are likely to

take several seasons of repeated cropping to occur. Intensive use of nitrogen fertilisers through buried drip systems is also likely to generate areas within the root-zone where repeated flushing has accelerated chemical changes to the point where uptake of nutrients such as Phosphorus is impeded. It is therefore important that tomato growers remain aware of the soil characteristics that effect the availability of Phosphorus and other nutrients in their soil.

Project Evaluation

Contents
Background information to the evaluation
Program Logic
Evaluation aims and key evaluation questions
Evaluation method
Discussion

Program Logic

Level	Development
SEEC (Social, Economic & Environmental conditions)	**ICM is used to increase the sustainability of the fresh market tomato industry** **Social:** Community regards industry highly because they are being more responsible towards the environment. Community views product as high quality and safe. The fresh tomato industry is viable and major contributor to Labor use. Broader community knowledge – greater research knowledge **Economic:** improved yield and reduced costs of inputs and generate more income for the area **Environmental:** no wastage of inputs (pesticides & fertilisers). Environmental benefits resulting from this project will include the maintenance of biodiversity of insect fauna by permitting populations of beneficial and non pest species to coexist within tomato crops, as well as reducing excess nutrient and pesticide flows in the environment
Practices (changes adopted by intermediate users & results of intermediate users work)	Practices which need to be adopted: Monitoring tools (including SAP, soil testing, resistance testing, weather data, pest phenology) used widely How do necessary practices compare with current baseline practices: New practices will see growers reacting to monitoring whereas current practices use set programs Consequences for the immediate users of the research findings: Efficient use of fertilisers and pesticides – Optimal use of inputs to meet crop requirements and increase in yield and quality of fruit – leading to increased profits Use fertiliser benchmarks and SAP testing to determine fertiliser applications Use results of resistance testing and resistance management strategy & guidelines to apply insecticides Use monitoring and *Helicoverpa* lifecycle to improve timing of insecticide applications
KASA (Knowledge, Attitude, Skills & Aspirations)	**Knowledge** – Better understanding of: chemical groups and chemical use, amount & type of fertiliser to apply and the timing of fertiliser application, Helicoverpa life cycle and how this effects the timing of chemical applications, resistance management and resistance levels in the northern Victoria **Attitudes** – Willingness to change their chemical (insecticide & fertiliser) programs to meet / match crop requirements rather than exceeding them. Using chemicals as an input rather than as insurance. Willingness to improve & learn **Skills** – Need to be able to monitor crop requirements and record keeping **Aspirations** – Better manage crop inputs. Manage crops and the environment more sustainable. To be seen as being environmentally friendly
Reactions	Dissatisfaction with current spray programs (some chemicals do not appear to be working), fertiliser programs and *Helicoverpa* control Surprise that there is resistance / surprise at the level of resistance
Participation (dissemination activities)	Dissemination activities: Poster developed on chemical groups, Workshop on chemical use and fertigation, Resistance management strategy developed and distributed to growers, Industry reporting, Seasonal updates, one on one discussions with growers, Steering committee, Web site

Activities (findings & activities)	Influence of migration for *Helicoverpa* in northern Victoria Levels of resistance for *Helicoverpa* in northern Victoria Genetic differences / similarities to the rest of Australia Nutrient requirements of fresh market tomatoes Understanding of targets for chemical (insecticide and fertiliser) application – knowledge of current practices and difference between current practices and targets for chemical application Links between pests and disease incidence and plant nutrition Research activities needed: Monitoring crops for *Helicoverpa* (moths & eggs), Monitoring SAP levels, Genetic testing, Resistance testing Specific issues or problems addressed: Presence & extent of resistance in the district. Timing, rates and efficacy of chemicals (insecticides & fertilisers) – applying the correct rates at the right time to meet crop requirements
Resources	Research & Extension staff: Joanne Dawson, Murat Top, David Williams, Bill Ashcroft, Cathy Mansfield, Lucinda Gibson + Casuals. Collaboration with Queensland University and Robin Gunning NSW agriculture and participating farmers Existing Knowledge: Previous fertigation project and IPM project + further reading Materials: Lab consumables and field equipment, resistance kits, field site ISIA Budget: Project funded by Industry, HAL and DPI

Aims of Evaluation

To assess the impact of research and knowledge gained in integrated crop management for fresh market tomato growers.

Key Evaluation Questions

1. To what extent have attitudes to IPM changed (impact)

2. To what extent do growers use information provided from this project
Was grower understanding of key concepts such as: resistance, timing of chemicals, rotation of chemicals, migration and fertigation improved as a result of this project.

3. What did we learn from this research project

Methods used in the Evaluation

Semi-structured interviews, IPM status report, Chemical and fertigation records and discussions with growers on an one on one basis or as a group have been used to discuss the above questions

Limitations of the Evaluation

- The project team conducted this evaluation. This could have resulted in some bias in interpretation because of the involvement in the project.
- For the most part practice change was expected to occur as a result of this project, once growers had been given all the information / results, a resistance management strategy for *Helicoverpa* and recommendations on monitoring and timing chemicals and fertilisers and not during the life of the project. An increase in knowledge of key concepts in IPM and awareness that current practice can and needs to be improved, were expected in this project.
- The evaluation depends highly on qualitative data interpretation

Discussion

Knowledge of pests and beneficials in the crop:

We have provided growers with a poster, which has the main pests and beneficials present in fresh market tomato crops. When asked about whether the poster is useful we got a positive response from growers, most saying that it has helped them to identify pests and beneficials.

Timing Chemical Applications:

Typically, the spray records of participating growers indicate that chemicals have not been applied to align with critical oviposition periods. Harvest assessments show a large variation in damage to crops. Looking at the spray records, egg counts and resulting damage it is clear that the current calendar spraying approach means that some chemicals miss peak egg lays and have very little affect on the population and others hit peak egg lay and significantly reduce the population. This approach to chemical application puts the crop at considerable risk of damage.

In a growers meeting, graphs which illustrated when eggs where laid and when chemicals where sprayed was shown. The graph demonstrated that many sprays were missing peak egg lays and therefore they were not significantly reducing the pest population. There was some surprise shown by growers that many of the chemical applications were missing the peaks. A discussion on monitoring and using this to time chemical applications followed.

The project has developed a sampling plan that will provide growers with information on pest abundance when used to monitor crops. Information on pest abundance can then be used to make a decision on when to spray crops. This approach could provide growers with a better way of managing *Helicoverpa* than the 'hit or miss' approach of calendar spray programs. The success of this is going to depend on having scouts who are willing to use this approach.

Rotating Chemicals and Resistance:

While there has been some attempt by a few growers to rotate chemical groups this cannot be said for all growers. Also one of the key concepts which we tried to impart to the industry is that because of migration (both short and long distance) rotating chemical groups needs to be aligned to a resistance management strategy. A resistance management strategy is a window based approach to using chemical groups, where each group is used only for a certain time period (window).

There is however an increased awareness by growers of resistance. Again the level of understanding of resistance varies greatly in the industry. Understanding of resistance ranged from those with very little understanding to those with excellent understanding, with most growers falling somewhere in the middle.

With some chemical groups either removed from use or restricted to *Helicoverpa punctigera* due to resistance, growers now know that their practices need to change. There is also awareness that resistance needs to be monitored on a regular basis. Continued monitoring of resistance was put into a new project by request of the industry.

Although growers feel that current controls are working in keeping pest populations under control they acknowledge that with resistance increasing and chemicals being removed from the market they need to change their practices. Growers know that resistance management is a step that they need to take and that they also need to look at alternative control methods. Now that an insecticide resistance management strategy has been developed for *Helicoverpa* the value of using this to rotate chemical groups and control resistance needs to be promoted with the industry

Migration
Growers are aware that migration can bring resistant individuals into the region and therefore increase resistance. While long distance migration can increase resistance this project has given growers a greater understanding of the influence that short distance migration can have on resistance.

Fertigation
All participants in the trials (75% of growers, which produce approx. 95% of total production) had an increased awareness of the importance of nutrient management. Participants in the monitoring program showed keen interest in the results, and used them to adjust their fertiliser regimes. Nutrient monitoring using petiole sap analysis has also been accepted, and is becoming routine practice with some growers (50% of growers). The value of locally developed nutrient benchmarks was also recognised, with the information made available to local service providers who supply diagnostic advice on crop management to the industry.

Results of the fertigation studies would have been better informed had the participating growers been willing or able to supply accurate records of their fertigation practices. While some were unwilling to do so for reasons of competitive advantage, it was clear that nearly all growers did not accurately record their applications, and this is an area for improvement in the industry.

Conclusion

For the most part practice change was expected to occur as a result of this project, once growers had been given all the information and not during the life of the project. An increase in knowledge of key concepts in IPM and awareness that current practice can and needs to be improved, were expected.

Surveys of growers have shown that there is still a strong influence from older generations on the farming practices of fresh market tomato growers. There is a better understanding overall of the key elements of integrated pest management. However some of the fundamentals of integrated pest management such as using monitoring to time chemical applications has so far had a poor uptake by growers, growers sticking to calender spray programs despite some of them monitoring for pests. Growers do understand that their current practice of controlling pests solely with chemicals will need to change in the future as chemicals are removed from the market and resistance increases.

Investment by the industry into a research project on trap plants and attractants, that could provide new tools for managing *Helicoverpa*, shows that growers

understand the results of this project and that alternative to current controls need to be investigated.

A lack of fertigation records has limited our ability to evaluate the fertigation work.

Technology Transfer

Poster

- Mansfield, C and Dawson J (2003). Chemical groupings to assist with the resistance management of Helicoverpa. Given to growers at the FTIDC meeting in June 2003, also sent out to growers not attending this meeting.

Newsletters

- Top, M (2003). Using groundwater for fresh market tomatoes. December issue 1
- Dawson, J. (2004). Resistance – what is it and how can we reduce the risk. January issue 2
- Dawson, J. (2004). Migration and its impact on crop management. February issue 3
- Top, M. (2004). Fertigation management of fresh market tomatoes. April issue 4
- Dawson, J & Top, M. (2004). Western flower thrips and tomato spotted wilt virus. May issue 5
- Top, M. (2005). Fertigation results for the ICM project. March issue 6
- Dawson, J. (2005). Resistance results and the potential of trap plants and attractants. April issue 7

Workshops

- Resistance management workshop for growers – 20th May 2003

Conferences

- Mansfield, C. M and Dawson, J. C (2003) Poster presentation*: Helicoverpa* Spp. control and insecticide resistance in the Northern Victorian Fresh Market Tomato crops. Australian Entomology Conference May 2003 Sydney

Presentations / reports to growers

- FTIDC – Dec 17th 2002- Outline of ICM project and the work that will be done in the first season
- FTIDC & AGM 27th June 2003 – Summary of first season, what trials where conducted and results so far, Evaluation plan for ICM project and next seasons work
- FTIDC - 14th November 2003 – Project review since June 2003: Analysis of results and work for the 2003-2004 season
- FTIDC & AGM – May 14th 2004 – Results from the 2003-2004 season, work for the 2004-2005 season and a workshop on ideas for future research in the fresh tomato industry
- FTIDC – Dec 7th 2004 – Results so far from the 2004-2005 season, further work this season and proposed new projects
- FTIDC and AGM – May 20th 2005– Resistance testing, timing and a resistance strategy and nutrition results. Also discussion on new project on trap plants and attractants
- Weekly updates on trial work to participating growers
- Seasonal updates to growers participating in the trials on their results

Refereed Scientific Papers

- Dawson, J, Hamilton, A, Mansfield, C (in press). Dispersion statistics and a sampling plan for *Helicoverpa* (Lepidoptera: Noctuidae) on fresh market tomatoes (*Lycopersicon esculentum*). Australian Journal of Entomology

- Hamilton, A. J, Versace, V, Hepworth, G, Stagnitti, F, Dawson, J, Ridland, P. M, Endersby, N. M, Schellhorn, N. A & Mansfield, C. (in press). Attending to risk in sequential sampling plans. Wessex Institute of Technology Transactions on Biomedicine and Health 9

Recommendations – Integrated Pest Management

The tomato industries total reliance on chemicals to control pests is creating problems, which will only increase in the future. The costs of chemicals are increasing and there is a lack of new chemistry coming onto the market. There is also a growing awareness of the wider problems it creates, such as pesticide resistance and environmental issues. All of this is driving the search for alternatives to chemicals. The industry needs to investigate alternative control methods for managing pest problems. Trap crops and attractants could provide an alternative for controlling the primary pest species *Helicoverpa* as well as secondary pests.

Recommendations – Nutrient Management

Monitoring:

Regular monitoring of petiole sap nutrient levels is recommended to Goulburn Valley tomato growers, as a tool to help them schedule fertiliser applications. Test results can be compared to the benchmarks developed through this project, and nutrient applications adjusted accordingly. These benchmarks are based on data taken from four seasons for indeterminate, and one season for determinate tomato crops in the Goulburn Valley. While these figures will provide Goulburn Valley tomato growers with a much better picture of crop nutrient requirements, their accuracy is limited by the available data set – particularly for determinate crops.

Total nutrient requirements:

The total amount of nutrients applied should match that removed by the crop less any initially present in the soil. Nutrient removal will vary with each field and management circumstance, but the results of this project provide a general guide that is consistent with figures obtained elsewhere. During the 2003/4 season, four trellis crops yielding an average of 108 t/ha removed 204 kg N, 22 kg P and 255 kg potassium per hectare. 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 requirements. Pre-planting soil tests are also important to quantify any residual nitrogen that may be available.

Timing of fertigation:

It is important to time the application of nutrients to meet the demands of the crop. Hegde (1997) suggests that the periods of greatest nutrient requirements for NPK is from about ten days after flowering to just before the fruit begins to ripen. However, our results indicate that high rates of nitrogen applied during early flowering periods may impact negatively on fruit size and yield. Sap calcium was negatively correlated with sap phosphorus, and sap phosphorus was found to be limiting yield in first three years of this study.

The quantity of nutrients to be applied depends on the yield potential of the cultivar, the level of available nutrients in the soil, growing conditions and crop management. The fact that vegetative and reproductive growth stages overlap, particularly in trellis tomato crops, requires on-going and careful nutrient management to optimise growth and productivity. Fertigation (application of fertilisers through drip irrigation) is an effective means of achieving this degree of control, as well as for reducing

wastage of fertiliser which adds cost to the grower and can contaminate the environment.

Form of nutrient:

Nitrogen, potassium and calcium are commonly applied through fertigation systems to tomato crops in the Goulburn Valley. While the benefits of applying nitrogen are self evident, local soils are rich in potassium and large amounts of calcium and Phosphorus 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, can limit yield. Results of a single year study failed to demonstrate any significant effect of different nutrient strategies (involving N, P, and Ca) on yield or fruit size. Phosphorus still appeared to be limiting yield at some sites however, so further investigation of this question may be warranted. The alternative, to supply higher levels of P either pre-plant or through the drip system, is feasible but may not be sustainable in the long term.

Commercial information providers:

These results and recommendations should be promoted to fertiliser merchants and agricultural service providers, who provide diagnostic advice to growers in crop nutrition.

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Appendix 1

Fertiliser application rates applied in trial program of development of P fixation in the 2002/3 season.

		T1			T2		T3				T4			Total amount per application				
		Calcium	Potassium	Muriate	Urea	Potassium	Calcium	Potassium	Urea	Muriate	Urea	Potassium	Urea	CaNO3	KNO3	Mur K	Urea	Urea P
WEEK	DATE	Nitrate	Nitrate	of Potash		Nitrate	Nitrate	Nitrate	P	of Potash		Nitrate	P					
1	22/11/2002	121	239	16										121	239	16		
					100	245									245		100	
							121	121	94					121	121	94		
											69	245			245		69	
3	6/12/2002	830	628	30										830	628	30		
					264	462									462		264	
							830	228	177					830	228	177		
											180	462			462		180	
5	20/12/2002	938	700	40										938	700	40		
					294	620									620		294	
							938	306	238					938	306	238		
										1060								1060
											201	620	1060		620		201	1060
7	3/01/2003	1000	741	47										1000	741	47		
					311	735									735		311	
							1000	363	282					1000	363	282	0	
											107	379			379		107	
9	17/01/2003	1015	752	52										1015	752	52		
					316	805									805		316	
							1015	397	309					1015	397	309	0	
											216	805			805		216	
11	31/01/2003	983	732	53										983	732	53		
					307	830									830		307	
							995	410	310					995	410	310	0	
										1060								1060
											210	830	1060		830		210	1060
13	14/02/2003	905	681	52										905	681	52		
					286	812									812		286	
							905	401	312					905	401	312	0	
											195	812			812		195	
15	28/02/2003	780	599	48										780	599	48		
					251	748									748		251	
							780	370	287					780	370	287		
											172	748			748		172	
17	14/03/2003	608	486	41										608	486	41		
					204	641									641		204	
							608	316	246					608	316	246		
											139	641			641		139	
19	28/03/2003	390	342	31										390	342	31		
					144	489									489		144	
							390	241	188					390	241	188		
											98	489			489		98	
	TOTAL	7,570.0	5,898.7	408.9	2,477.4	6,386.6	7,572.0	3,153.0	2,120.0	2,443.0	1,587.0	6,031.0	2,120.0	15,142.0	21,469.3	2,851.8	4,064.4	4,240.0
		7.6	5.9	0.4	2.5	6.4	7.6	3.2	2.1	2.4	1.6	6.0	2.1	15.1	21.5	2.9	4.1	4.2