Know-how for Horticulture™

Spray technology for optimum pesticide application in macadamias

Henry and Jenny Drew,
Graham Betts,
and Glenn Geitz

HJ & JM Drew Consultants,
Ask GB Consultant,
and Queensland Department of Primary Industries

Project Number: MC00041

MC00041

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the macadamia industry.

ISBN 0 7341 0759 5

Published and distributed by:
Horticultural Australia Ltd
Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

Horticulture Australia

Horticulture Australia

Spray technology for optimum pesticide application in macadamias.

Final Report
Project No. MC00041

By

Henry and Jenny Drew[1], Graham Betts[2] and Glenn Geitz[3]

[1] HJ & JM Drew Consultants, [2] Ask GB Consultant
[3] Queensland Department of Primary Industries

Horticulture Australia

Spray technology for optimum pesticide application in macadamias.

Final Report
Project No. MC00041

Henry and Jenny Drew
(HJ & JM Drew Consultants)

Horticulture Australia
Project No. MC00041

October 2003.

This report outlines the results of spray application trials carried out using several spray technologies in mature macadamias in south-east Queensland. It discusses the critical factors for each technology and the implications for coverage and chemical concentrations.

Project Leader
Dr. Henry Drew,
283 Hunchy Rd,
Hunchy,
QLD 4555.

Tel: 07 5445 0032
Fax: 07 5445 0940

This research was funded by:

Horticulture Australia

and

The Australian Macadamia Society

AUSTRALIAN MACADAMIAS®

Spray technology for optimum application in macadamias.

ABBREVIATIONS

AMS	Australian Macadamia Society
APVMA	Australian Pesticides & Veterinary Medicines Authority
CDA	Controlled droplet application
DF	Double-fan
DS	Double-sided
EHVD	Equivalent high volume dose
ha	Hectare
hf	high fan speed
IPM	Integrated pest management
LD_{50}	Lethal dose required to kill 50% of a test species
lf	low fan speed
LP	Low-profile
MT	Metric tonne
NIS	Nut-in-Shell
NRA	National Registration Authority (now the APVMA)
NSW	New South Wales
PI	Penetration index
POR	Point of runoff
QDPI	Queensland Department of Primary Industries
SEQ	South East Queensland
SF	Single-fan
SKR	Sound kernel recovery
SS	Single-sided
VMD	Volume median diameter

MEDIA SUMMARY

Spray application in macadamias could be considered a worst-case spraying scenario as trees are often grown on steep slopes and can reach heights of 8-10m with dense canopies. A huge range of equipment is available to spray such trees but their underlying mechanisms are poorly understood. The project investigated the appropriate spray volumes for high volume Dilute spraying and concluded that a spray volume of 6.0 L per 100 cubic metres of canopy was a safe, conservative estimate. This volume should be used as the basis for calculating the spray concentration for low volume Concentrate sprays. The project also assessed several air-assisted technologies and the effects of changes in sprayer calibration. The trials found that spray volume, air volume and tractor speed had little effect on coverage. The trials showed that it was almost impossible to achieve good coverage at 6 m height with a low-profile airblast with hollow cone jets. Fans on towers showed promise but droplet size and air ducting appeared critical. The trials suggested that for hollow cone jets air-displacement within the canopy was less important than the effects of drift. Changing the point of delivery of droplets and increasing the kinetic energy / momentum of droplets may be ways to improve carriage to the top of the canopy. Such changes may be achieved by increasing the use of solid cone or solid stream jets at 15-20 bar pressure targeting the top of the canopy. Given the difficulties of reaching and penetrating the top of the canopy more work needs to be done on the effects of top and side canopy pruning and within canopy spraying.

TECHNICAL SUMMARY

Spray application in macadamias could be considered a worst-case spraying scenario. Trees are often grown on steep slopes and can reach heights of 8-10m with very dense canopies. The trials reported here were carried out in mature macadamia orchards at Glasshouse Mountains and at Boreen Point, SE Queensland, in the cultivar 344. Trees were more than 8 m tall with a total canopy volume of 40-53,000 cubic metres. Coverage was assessed by analysis of recovery of Helios fluorescent dye on leaves at six positions within the canopy.

Overall assessment of sprayer performance was complicated by differences between positions within the canopy. Two indices of canopy penetration and height distribution were used to compare treatments and technologies.

The project investigated the appropriate spray volumes for high volume Dilute spraying to meet new APVMA product label guidelines on calculation of Concentrate rates. The results suggested that a Dilute spray volume of 6.0 L per 100 cubic metres of canopy was a conservative benchmark which would permit safe and effective application of Concentrate sprays. This volume should be used as the basis for calculating the spray concentration for low volume Concentrate sprays in all macadamia varieties.

A huge range of spray machinery is available to spray large trees but their underlying mechanisms were poorly understood. The project built on work by the Queensland Department of Primary Industries and the Centre for Pesticide Application and Safety at the University of Queensland on calibration in pomefruit and citrus. The project assessed several air-assisted technologies and the effects of changes in sprayer calibration variables. The sprayers included single-sided (SS) and double-sided (DS) single-fan (SF) low-profile (LP) airblasts, a double-fan (DF) DS LP airblast, and both airshear and spinning disk DS sprayers with towers.

The trials found that spray volume, air volume and tractor speed had little consistent effect on coverage and that it was almost impossible to achieve good coverage at 6 m height with a low-profile airblast with hollow cone jets. The trials suggested that different processes were occurring in different parts of the tree and that air-displacement within the canopy was less important than the effects of gravity and drift. This was particularly applicable to the middle and top portions of the canopy.

Changing the point of delivery of droplets and increasing the kinetic energy / momentum of droplets may be ways to improve carriage to the top of the canopy. Such changes may be achieved by increasing the use of solid cone or solid stream jets at 15-20 bar pressure targeting the top of the canopy. Individual straight-through fans on towers also showed promise but droplet size, kinetic energy and air ducting appeared critical.

Simple models, taking air carrying capacity and gravity into account, are discussed to explain why increasing spray volume had little effect on the top of the canopy. Given the difficulties of reaching and penetrating the top of the canopy more work needs to be done on the effects of canopy pruning and within canopy spraying. This report has been written with an emphasis on the "story" and the "interpretation" of the underlying processes rather than on the individual data or technology. The data showed high variability, some causes of which we identified, and highlighted the extreme complexity of the spraying process in large canopies.

1. INTRODUCTION

1.1 The macadamia industry

The macadamia industry on the east coast of Australia is the second largest in the world, with an estimated production in excess of 30,000 tonnes of nuts in 2001. A range of invertebrate pests and husk spot disease can cause both significant crop losses and increases in processing costs. The pests vary widely in their habits and susceptibility to sprays, ranging from the mobile active spotting bug to the sedentary felted coccid. Trials of non-chemical controls, including use of native and introduced parasites, are underway but the majority of growers still control their pest problems using pesticide application. Husk spot disease is also an insidious problem currently controlled by systemic fungicide sprays, sprayed as a precaution up to 10 weeks before symptom expression. The range of pests and the macadamia orchard environment create exacting requirements for spray application.

1.2 Spraying large tree crops

Currently several tree crops in Australia are grown commercially to a very large canopy size. These include avocados, macadamias and pecans. Pecans are the tallest canopy but are usually grown on flat land where very tall towers can be used. Their canopies are also relatively open compared with avocados and macadamias. Spraying a mature macadamia tree could be considered a worst-case scenario for tree crop spraying. Macadamias can grow into very large canopies, up to 10m tall, with canopy volumes in excess of 60,000 cubic metres per hectare. Add to this a dense canopy structure, hard to wet leaves, nuts in dense clusters and orchards on slopes up to 15^0 and one can see there are challenges to overcome.

Little hard data has been gathered on grower spray practices in large tree crops but two preliminary studies have been done. Battaglia and Harden (c.1997) gathered very general data using a postal survey of macadamia growers. Their study showed that most growers were using airblast (with hydraulic nozzles) or airshear (with twin fluid nozzles) sprayers. An avocado telephone survey by Drew (2000) of the spraying practices of 50 avocado growers on the Sunshine Coast of Queensland provides an interesting comparison with the macadamia postal survey (MPS) by Battaglia and Harden (c.1997). An in-field calibration survey, also by Drew (2000), looked in more detail into the individual setup of sprayers and pesticide rates used in both avocados and macadamias.

1.2.1 The Avocado Telephone Survey (ATS)

Drew (2000) found that ninety percent (45/50) of avocado growers were using ground sprayers, of which 18% were using handguns and the remaining 82% using air-assisted sprayers. Several reasons were given for continuing use of high pressure handguns, including lack of capital, poor economic viability of small orchards, control of drift and a need to apply pesticides quietly because of the possibilities of complaints from neighbours.

Of the 74% (37/50) growers using air-assisted sprayers 76% were using airblast sprayers with hydraulic nozzles, 19% were using airshear and 5% were using CDA. This is very close to the proportion of growers in the MPS using airblast sprayers (73%). A greater proportion of growers in the MPS used low volume airshear (33%) or CDA sprayers (14%) than in the ATS. This could be explained by differences between target pests and diseases, the higher requirement for fungicide use in avocados, or variations in orchard size. Since average orchard sizes are generally far greater in macadamias than in avocados the economic benefits of using dedicated low volume sprayers would be greater in macadamias.

Sixty eight percent (31/45) of avocado sprayers were bought new while 24% (11/45) were bought with the property. Only 4% (2/45) were bought second-hand independently of the property. Eighty one percent (30/37) of the air-assisted ground sprayers were used with a single-sided conveyor ducting all the air to one side. Only 19% (7/37) of growers were using double-sided spraying.

Drew (2000) found that there was a very diverse understanding of the concept and practice of calibration. Growers in the ATS were asked about "calibration" of their sprayers, but the term was not defined and it became apparent that it had several meanings, ranging from calculation of spray volumes and chemical rates to simply cleaning the nozzles. Of the growers using air-assisted spraying 45% (17/37) said they had calibrated their machines themselves at some time. Overall 47% (17/37) of air-assisted sprayers were calibrated by a third party, of which 24% (9/37) were by spray machinery representatives, 11% (4/37) by QDPI extension officers, 3% (1/37) by consultants and 8% (3/37) by other persons (mostly other growers or family). In comparison in the MPS 32% of sprayers were calibrated by a third party, but none by QDPI extension officers.

Of the growers who used air-assisted spraying 32% said that their sprayer was calibrated within the last 2 seasons. A further 32% (12/37) said they were calibrated in the last 5 years, and 12% (4/37) more than 5 years ago. In comparison, in the MPS 52% said they calibrated their sprayers annually. The high percentage of growers who said their sprayers <u>had</u> been calibrated but were unsure <u>when</u> (19%), does cast some doubt on the results, but suggests that calibration is not a high priority for many growers. Five percent of growers in the ATS using air-assisted sprayers, and 7% in the MPS, said their sprayers had never been calibrated.

1.2.2 The In-Field Calibration Survey (IFCS)

Drew (2000) also carried out an In-Field Calibration Survey (IFCS), involving an in-depth analysis of avocado and macadamia growers orchard sprayer calibrations, gathering data on target canopies, speeds, nozzles, pressures and application volumes. This data was analysed using a simple spreadsheet.

CANOPIES

Average tree canopy volumes were 211 m^3 (Std. Dev. 117) and 122 m^3 (Std. Dev. 66) in avocados and macadamias, respectively. The largest macadamias trees had a volume of 384 m^3 compared with 576 m^3 for avocados. Overall 67% of avocado, and 58% of macadamia trees had canopy volumes between 100 and 300 m^3 per tree, as shown in TABLE 1.1. The large number of smaller macadamia trees (below 100 m^3) may reflect a higher level of young plantings than in avocados.

TABLE 1.1 Percentage distribution of average tree canopy volumes in the IFCS.

Canopy volumes in m^3 per tree.	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
below 100	18	18	39	39
101 - 200	26	44	50	89
201 - 300	41	85	8	97
301 - 400	12	97	3	100
above 400	3	100	0	100

Average orchard canopy volumes were 30,950 m^3 (Std. Dev. 15,791) and 27,208 m^3 (Std. Dev. 11,056) per hectare in avocados and macadamias, respectively. Overall 32% of avocado, and 70% of macadamia orchards had canopy volumes between 25,000 and 35,000 m^3 per hectare, as shown in TABLE 1.2.

Mechanical hedgerow pruning of macadamias is increasing in popularity and may explain the low proportion of macadamias with canopies above 35,000 m^3 per hectare volume. Another contributing factor may be that production falls more rapidly in macadamias with closed canopies than in avocados, i.e. avocado growers can maintain larger productive canopies.

TABLE 1.2 Percentage distribution of average orchard canopy volumes in the IFCS.

Canopy volumes in m^3 per hectare	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
below 5,000	3	3	3	3
5-15,000	18	21	10	13
15-25,000	8	29	28	41
25-35,000	24	53	42	83
35-45,000	29	82	9	92
above 45,000	18	100	8	100

These canopy volumes are very high when compared with quoted canopy volumes for some intensive European orchard systems, e.g. 6,900-10,900 m^3 per hectare for apples. Apples in Queensland are generally larger, with canopy volumes of 13,400-18,200 m^3 per hectare, but these are still low in comparison with macadamias.

NOZZLES & PRESSURES

Most growers were using hollow cone ceramic nozzles, with the remainder using a mix of solid and hollow cones. Average pressures were 223 psi [1] (Std. Dev. 115) and 195 psi (Std. Dev. 98) for avocados and macadamias, respectively. About three quarters of growers were using between 101 and 300 psi, as shown in TABLE 1.3. This is consistent with recommendations in recent QDPI literature for other tree crops (Hughes *et al.*, 1997; Battaglia *et al.*, 1997).

TABLE 1.3 Percentage distribution of spraying pressures used in the IFCS.

Pressure in psi	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
up to 100	15	15	17	17
101 - 200	29	44	36	53
201 - 300	35	79	38	91
301 - 400	21	100	8	99
above 401	0	100	1	100

Pressures below 100 psi were generally for non-hydraulic nozzle sprayers such as airshear or CDA sprayers. The very small percentages using above 400 psi does cast some doubts on the usefulness and relevance of relatively recent comparative research trials by QDPI in macadamias using 430 psi (Broadley *et al.*, 1993a, 1993b).

[1] Pressures are presented in pounds per square inch (psi) because this is the unit usually used by growers. 1 bar = 100 kPa = 14.5 psi.

Average calculated nozzle outputs from one side of the sprayer were 21.5 L per minute (Std. Dev. 10) and 19.0 L per minute (Std. Dev. 8) in avocados and macadamias, respectively. Given the slightly higher average pressures used by avocado growers this suggests that both groups of growers were using a similar range of nozzle sizes.

TRACTOR SPEEDS

Average speeds were 2.9 kph (Std. Dev. 0.8) and 2.7 kph (Std. Dev. 2.01) in avocados and macadamias, respectively. Approximately 70% of growers in both crops were travelling at below 3 kph, as shown in TABLE 1.4. Based on the formula presented by Cunningham *et al.* (c.1996b, p.21), to achieve full penetration out of the far side of the tree canopy at speeds above 3.0 kph in mature tree crops (e.g. 5 m wide x 6 m high) would require a very high volume of air (e.g. 90,000 m^3 per hour) and is outside the capability of most commercial sprayers (Broadley, 1992, p.109). If the air displacement model of spraying is accepted then this implies that 20 to 30% of growers surveyed were travelling too fast. Higher speeds in macadamias may reflect the larger orchard sizes and longer individual row lengths than in avocados.

TABLE 1.4 Percentage distribution of tractor speeds used in the IFCS.

Speed in km per hour	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
up to 2.0	12	12	8	8
2.1 - 3.0	59	71	64	72
3.1 - 4.0	17	88	19	91
4.1 - 5.0	12	100	8	99
above 5.1	0	100	1	100

These results are comparable to the results of the MPS. However while the MPS found that 12% of growers used variable speeds, such practices are incorporated in the IFCS as separate cases. Of the remaining MPS growers 32% used below 2.5 kph and 67% used 2.5 to 5.0 kph. As in the IFCS only 1% used over 5 kph.

SPRAY VOLUMES

Growers often discuss their spray volumes in terms of litres per tree taking no account of tree size. The concept is essentially meaningless but has regularly appeared in grower extension literature. To continue this lamentable trend - average spray volumes were 5.5 L and 3.9 L per tree in avocados and macadamias, respectively! The IFCS and MPS gave comparable results with only 10-15% of macadamia growers applying less than 2 L/tree or more than 8 L/tree, as shown in TABLES 1.5 & 1.6.

TABLE 1.5 Percentage distribution of average spray volumes per tree in the IFCS.

Spray volume in litres/tree	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
up to 2.0	6	6	14	**14***
2.1 - 4.0	26	32	41	55
4.1 - 6.0	30	62	35	90
6.1 - 8.0	23	85	4	**94**
8.1 - 10.0	9	94	6	100
above 10.1	6	100	0	100

* Highlighted figures are very similar to those found in the MPS, TABLE 6.

TABLE 1.6 Percentage distribution of average spray volumes per tree in the MPS.

Spray volume in litres/tree	Macadamia < 5 m tall %	Macadamia < 5 m tall cumulative %	Macadamia > 5 m tall %	Macadamia > 5 m tall cumulative %
up to 2.0	33	33	11	**11**
2.1 - 5.0	49	82	36	47
5.1 - 8.0	16	98	39	**86**
above 8.0	2	100	14	100

Note: Trees more than 5 metres tall would probably have a canopy volume of 80-100 m^3 per tree. The point-of-runoff for these trees would be a minimum of 6-8 L per tree, suggesting that at least 58% of growers are using low volume spraying. This is a lower percentage than shown by the IFCS but similar to the percentage from the ATS.

All growers using air-assisted sprayers were spraying their trees from both sides. Average spray volumes per hectare were 968 L (Std. Dev. 466) and 979 L (Std. Dev. 428) in avocados and macadamias, respectively. Overall 50-60% of growers used less than 1000 L/hectare and approximately 90% used less than 1500 L/hectare, as shown in TABLE 1.7. This really tells us little about coverage or runoff from the trees, but again suggests that most growers are in fact using low volume spraying.

TABLE 1.7 Percentage distribution of spray volumes per hectare in the IFCS.

Spray volume in litres/hectare	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
up to 500	12	12	11	11
501 - 1000	44	56	50	61
1001 - 1500	32	88	32	93
1501 - 2000	6	94	4	97
above 2001	6	100	3	100

Average spray volumes per 100 m^3 of canopy were 3.14 L (Std. Dev. 1.81) and 3.49 L (Std. Dev. 1.45) in avocados and macadamias, respectively. Spray volumes ranged from 0.5 - 10.7 litres per 100 m^3 with more than 50% of sprays in both crops using 2.5-5.0 litres per 100 m^3, as shown in TABLE 1.8.

TABLE 1.8 Percentage distribution of spray volumes per unit canopy volume in the IFCS.

Spray volume in litres per 100 m^3 canopy volume	Avocado %	Avocado cumulative %	Macadamia %	Macadamia cumulative %
up to 2.5	38	38	24	24
2.51 - 5.0	56	94	58	82
5.01 - 7.5	3	97	18	100
above 7.5	3	100	0	100

Overall 82-94% and 97-100% of sprays in both crops were "low volume" when compared with an estimated dilute spray volume of 5.0 or 7.5 litres per 100 m^3, respectively. Only 3% of avocado sprays using air-assisted sprayers appeared to be sprayed to point-of-runoff, compared with 23% of growers from the telephone survey who claimed to be using only high volume spraying. This is as expected, given (as previously mentioned) the inclusion of non air-assisted sprayers in the telephone survey. It may however also be an indication of the problem of description of high volume spraying based on individual perceptions of point-of-runoff.

The data suggests that as tree size increases the volume of water used by growers per unit of canopy decreases, and vice versa. Smaller trees are being sprayed well beyond point-of-runoff while larger trees are in some cases receiving very very low spray volumes. This could reflect the overall cost (in time and dollars) of high volume spraying in large canopies or the technical difficulties of achieving point-of-runoff in taller trees. In smaller trees the overall costs would be low, although the relative costs may be higher.

1.3 The need for further research in macadamias

As a result of the study by Battaglia and Harden (c.1997) the Australian Macadamia Society, the Australian Avocado Growers Federation and Horticulture Australia funded a series of grower and consultant spray workshops in Queensland, New South Wales and Western Australia (Battaglia, c.1998). These workshops were based on the successful workshops carried out in pomefruit and citrus by Cunningham *et al.* (c.1996a & b). The macadamia and avocado workshops were well received but identified a need for further research to better understand the critical spray parameters in macadamias. Battaglia and Harden (c.1997) concluded that "without detailed research in the specific tree canopies of these crops [avocado and macadamia] for spray coverage using a range of volumes and equipment types, firm recommendations on optimum sprayer configurations for growers are not possible". They listed the following key issues requiring further research (p.5):

- Matching application volumes and chemical doses to tree size. This requires addressing label shortcomings and requires significant input from experienced researchers, chemical manufacturers and the National Registration Authority.
- Developing strategies for canopy management that complement existing application equipment and encourage more efficient pesticide application.
- Providing specific information on the performance of specific types of sprayers, including airshear technology and other innovations such as under tree conveyors and multi-headed spray systems.
- Developing best practice strategies that can help reduce spray drift and minimise environmental contamination.

These issues were addressed in the planning of the MC00041 trials. The trials had originally been planned to investigate bio-efficacy, as measured by husk spot control, but this was simplified due to a reduction in the QDPI level of involvement in the project.

The workshops in pomefruit (Cunningham *et al.*, c.1996a & b) were based on research carried out under an industry-funded project called "Pesticide reduction in pomefruit towards 2000". The aims of this project were to increase pesticide deposit in the tree and improve coverage throughout the height and depth of the tree canopy, while reducing off-target losses and risks (Cunningham *et al.*, 1995). The trials in pomefruit showed that it was impossible to achieve good coverage at heights above 4 m in pomefruit using a low profile airblast sprayer (Dullahide, pers.comm.). Similarly in the UK Cross (2002) has pointed out that sprayer operators are still unable to make better adjustments to their airblast sprayers to suit their crops because of a lack of clear guidance on how this should be done. Cross also points out that many studies of spraying are of limited value because more than one variable had been changed, resulting in a confounding of the true effects of treatment factors. These were key considerations in developing the trials in MC00041.

2. GENERAL METHODOLOGY

2.1 Trial design and sampling

The aim of the trials undertaken was to gain a better understanding of the critical factors involved in spray application in macadamias.

All treatments comparing technologies were assessed by quantitative recovery of Helios dye as used in recent QDPI trials in other crops, eg. citrus and pomefruit. A visual assessment method in the field, eg. using fluorescent dye as per Broadley *et al.* (1993a & b), was not adopted due to the subjective nature of the results and the likelihood of spray equipment manufacturer opposition. However some visual and automated assessments were made of water-sensitive papers and leaves, respectively. Also our results are compared with those of Broadley *et al.*(1993a & b) where relevant.

The limitations of the Helios recovery method were:

- Coverage for each treatment could not be readily assessed on-site, ie . trials could not be fine-tuned.
- Distribution of droplets on the leaf could not be assessed.
- Any anomalies could not be easily identified and corrected.
- Analysis relied solely on the time and expertise of QDPI Gatton staff.

The advantage of the Helios recovery method were:

- The method was proven and accepted by QDPI.
- The method gave quantitative results.
- The method was more acceptable to spray equipment suppliers.
- The method took into account very small droplets not visible to the naked eye.
- The method gave equal weight to both top and underside coverage.
- Leaf sampling bias was minimised since residues were not visible.

The aim of each trial was not necessarily to achieve optimum coverage but rather to determine the effects of sprayer speed (and hence air volume) and spray volume on recovery. There was no intention to compare sprayer models or brands for performance. An underlying assumption of the trials was that all sprayers could be effective if used within their operating limitations. The importance of those limitations to users were not the subject of investigation.

A critical concept for the trial plans was to ensure that different treatments were comparable based on changes to only a single variable. The basic treatment matrix, consisting of 5 treatments plus 1 manufacturers choice, was as shown in FIGURE 2.1. Due to limitations of funding it was not possible to do all 9 treatments.

FIGURE 2.1 Planned standard airblast treatment matrix.

Spray volume and speed	Low volume	Medium volume	High volume
Slow	--	✓	--
Medium	✓	✓	✓
Fast	--	✓	--

Manufacturers Choice
✓

The trial site setup and sampling procedures were as follows:

- Each trial block consisted of 3 rows of 25-30 trees, the middle row being the sample row.
- Each treatment was separated from the next by an unsprayed guard row.
- Treatments were not replicated.
- Six trees of similar size and canopy density were selected for sampling.
- The first 4 trees at each ends of the row were not sampled due to the possibility that the sprayer had not reached operating pressure at the nozzles.
- Samples of 12-15 leaves were taken at six positions in the inner (I) and outer (O) canopy at 3 heights, being 1.5-2.5 m (B), 3-4.5 m (M) and 6-7 m (T), from the eastern side of the canopy. In each position the 12-15 leaves were taken from at least 5 different branches.
- All samples were taken once the spray had fully dried, usually about 45 minutes after treatment.
- Leaf samples were placed into labelled paper sandwich bags and then into black plastic garbage bags.
- For overnight storage samples were kept in an air-conditioned room.
- One treatment generated 36 sample bags, ie. 6 x BO, BI, MO, MI, TO and TI.

2.2 Trial blocks and equipment

2.2.1 Trial Blocks

Trials were carried out in 5 different blocks on 3 farms on the Sunshine Coast. Most trials were carried out at Sahara Farms, Sahara Rd, Glasshouse Mountains in the block designated "Gowens 344", with only 1 treatment each in "Gowens 246" and "Gowens 741". Two treatments were applied at Terry Morgans farm, Sahara Rd, Glasshouse Mountains in a block designated "Morgans 344". Two full trials were carried out at Roger Arbuckles farm, Gilson Rd, Boreen Point in a block designated as "Arbuckles 344". The details of the orchard blocks are given below in TABLES 2.1, 2.2, 2.3, 2.4 and 2.5.

TABLE 2.1 Crop characteristics for "Gowens 344" - Sahara Farms Mountain Block.

Distance between rows and trees	9.0 x 4.5 m
Number of trees / hectare	247
Average tree height, length and width	8.0 x 4.5 x 6.0 m
Average canopy volume / tree	216 m^3
Average canopy volume / hectare	53,333 m^3
Row orientation and slope	N-S, gentle slope, north facing

TABLE 2.2 Crop characteristics for "Gowens 741" - Sahara Farms Back Block.

Distance between rows and trees	9.5 x 3.5 m
Number of trees / hectare	301
Average tree height, length and width	7.0 x 3.5 x 5.0
Average canopy volume / tree	123 m^3
Average canopy volume / hectare	36,842 m^3
Row orientation and slope	N-S, gentle slope, south facing

TABLE 2.3 Crop characteristics for "Gowens 246" - Sahara Farms Road Block.

Distance between rows and trees	10.0 x 6.0 m
Number of trees / hectare	167
Average tree height, length and width	9.0 x 6.0 x 7.0 m
Average canopy volume / tree	378 m^3
Average canopy volume / hectare	63,000 m^3
Row orientation and slope	N-S, gentle slope, north facing

TABLE 2.4 Crop characteristics for "Morgans 344" - Terry Morgan Road Block.

Distance between rows and trees	9.0 x 4.0 m
Number of trees / hectare	278 trees
Average tree height, length and width	7.0 x 4.0 x 6.0 m
Average canopy volume / tree	168 m^3
Average canopy volume / hectare	46,667 m^3
Row orientation and slope	N-S, gentle slope, north facing

TABLE 2.5 Crop characteristics for "Arbuckles 344" - Roger Arbuckle Central Block.

Distance between rows and trees	8.0 x 4.0 m
Number of trees / hectare	312 / ha
Average tree height, length and width	7.0 x 4.0 x 5.0 m
Average canopy volume / tree	140 m^3/tree
Average canopy volume / hectare	43,680 m^3/ha
Row orientation and slope	N-S, medium slope, south facing

2.2.2 Tractor speeds

Two different tractors were used, a Deutz DX7 at Gowens and Morgans at Glasshouse Mountains, and a John Deere 6400 at Arbuckles at Boreen Point. Tractor speeds were measured over a 50 m distance being the average of an uphill and a downhill run. In all cases the sprayer pto was engaged to simulate spraying conditions. The speeds for each tractor are given in TABLES 2.6 and 2.7.

TABLE 2.6 DEUTZ DX7 used at Gowens and Morgans.

Range and gear	Engine rpm	Speed (kph)
Low 1	2000	2.0
Low 2	2000	2.7
Low 3	2000	3.4
Low 4	2000	4.8
Low 5	2000	6.1
Medium 1	2000	4.2
Medium 2	2000	5.6
Medium 3	2000	7.3

TABLE 2.7 JOHN DEERE 6400 used at Arbuckles.

Range and gear	Engine speed (rpm)	Tractor speed (kph)
B1	1500	2.3
C1	1500	3.8
C3	1500	5.4
A4	1800	2.0
A4	2000	2.2
B2	2000	3.8
C1	2000	5.2

Note: The hydraulic pump for use with the CDA spinning disk sprayer could not be run consistently at 2000 rpm due to severe overheating.

2.2.3 Nozzles

The nozzles used in most trials were Albuz ATR ceramic hollow cones. These were selected because they are widely used across the industry and are of good quality. For comparison of nozzles in other trials we have used the QDPI figures for VMD and droplet spectrum published by Hughes *et al.* (c.1997) and Battaglia *et al.* (c.1997). This data (TABLE 2.8 and APPENDIX B), which generally gives higher VMD than manufacturers (TABLE 2.9), related to nozzle performance under a single testing regime rather than the various manufacturers different tests.

TABLE 2.8 QDPI flow rate and droplet size for Albuz ATR hollow cones @ 15 bar (Hughes *et al.*, 1997).

Jet Size	3.0 Blue (Bl)	2.3 Green (Gr)	2.0 Red (Rd)	1.5 Orange (Or)	1.2 Yellow (Ye)	1.0 Brown (Br)	0.8 Lilac (Li)
Flow rate (L/min)	4.06	2.94	2.30	1.62	1.24	0.78	0.61
D50 / VMD μm	**116**	**113**	**112**	**112**	**105**	**93**	**81**
0-70 μm *	26%	27%	27%	25%	24%	30%	38%
70-250 μm	68%	69%	69%	71%	75%	69%	61%
250-1000 μm	6%	4%	4%	4%	1%	1%	1%

* percentage of spray volume in the range

By comparison the manufacturers own data for Albuz ATR nozzles at 15 bar shown in TABLE 2.9 give a lower VMD and greater range than the QDPI figures. Neither of the methods used took into account the effects of airstream and the figures are therefore a rough guide only.

Flow rates and known droplet sizes for other nozzles used are given in TABLES 2.10 and 2.11.

TABLE 2.9 Manufacturers droplet size and spectrum for Albuz ATR hollow cones @ 15 bar (Albuz, 1989)

Jet Size	**3.0 Blue (Bl)**	**2.3 Green (Gr)**	**2.0 Red (Rd)**	**1.5 Orange (Or)**	**1.2 Yellow (Ye)**	**1.0 Brown (Br)**	**0.8 Lilac (Li)**
D10 μm	31	29	26	27	24	25	25
D50 / VMD μm	**114**	**94**	**88**	**79**	**71**	**64**	**61**
D90 μm	322	253	234	205	159	132	132

TABLE 2.10 Other nozzle types used (Hughes *et al.*, 1997).

Jet type and size	**Spraying Systems (SS) Visiflo TXVK 8 Gray @ 15 bar**	**Silvan 0.8 Disc & core Closed centre @ 15 bar**	**TurboDrop Orange & Green with air induction @ 15 bar**	**Albuz ATR 1.2 Yellow (Ye) @ 5 bar**
Flow rate (L/min)	1.20	2.94		0.98
D50 / VMD μm	**104**	**< 119**	**112-113**	**107**
0-70 μm *	27%		without air	18%
70-250 μm	72%		induction, ie.	82%
250-1000 μm	1%		very large	0

* percentage of spray volume in the range

TABLE 2.11 T5 Flow rates for Spraying Systems solid stream stainless steel.

Jet Size	**SS D1.5**	**SS D3**	**SS D4**	**SS D4**	**SS D6**	**SS D7**
Pressure (bar)	6	6	2	6	5	5
Flow rate per jet (L/minute)	0.92	1.60	1.61	2.79	5.79	7.88

Droplet size and % of volume in ranges were unknown as solid stream nozzles are usually used at low pressure and droplet formation does not occur.

2.2.4 Weather recording

Weather conditions were recorded immediately before or after each treatment using a Skyview Systems WM-918 electronic weather station supplied and calibrated by QDPI Gatton.

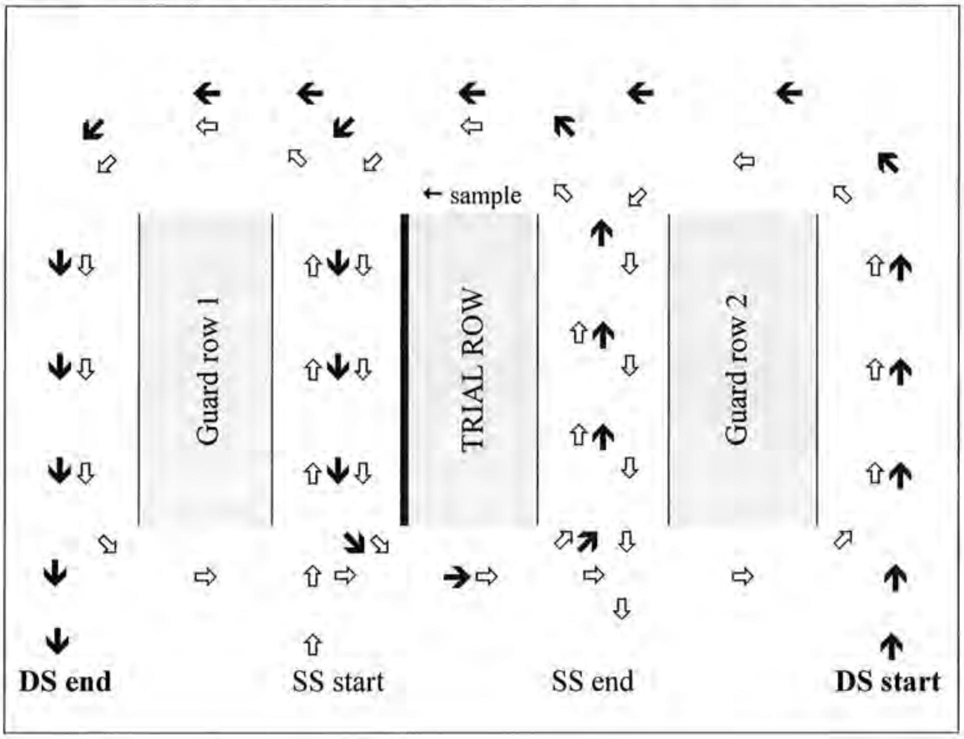
2.3 Dye mixing and spray procedure

The way in which dyes were mixed and sprays applied could have affected the results. For example the left and right hand sides of double-sided sprayers can vary widely. We therefore adopted the following a standard procedures to ensure variation was minimised:

1. Fill the spray tank to 2/3 the required volume (measured using an electronic flow meter).
2. Measure & add the required amount of dye, thoroughly rinsing the measuring cylinder into tank.
3. Continue to fill the tank using high pressure hose to aid mixing.
4. Travel to trial site (2-3 minutes @ 10-15 kph), natural agitation only.
5. At trial site begin tank agitation and spray for 1 minute to ensure all jets are working.
6. **For single-sided (SS) spraying:** Begin single-sided trial by spraying right side of Guard row 1 (3-4 mins @ 2 kph, 2-3 mins @ 3.4 kph), then left side. Then spray right side Trial row then left (Sampling) side. Then spray right side Guard row 2 then left side (see FIGURE 2.2).
   For double-sided (DS) spraying: Begin double-sided trial by spraying right side of Guard row 2 single-sided. Then spray left (Sampling) side of Trial row and right side of Guard row 1 double-sided. Then spray right side of Trial row and left side of Guard row 2 double-sided. Complete left side of Guard row 1 single-sided (see FIGURE 2.2).
7. Take spray sample from drain plug.
8. Open drain plug and drain tank en-route to refilling point.
9. Pressure hose clean the tank and drain prior to next treatment.

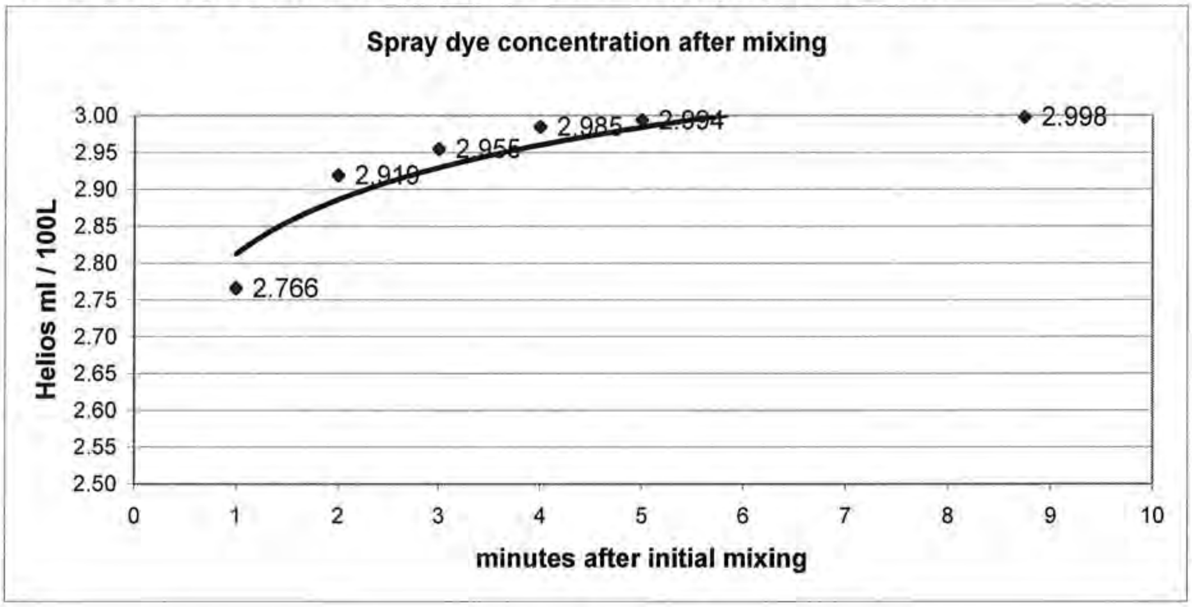
This procedure was adopted to ensure that the dye had fully mixed and cleared the hoses to the nozzles before application to the trial rows and that the LEFT side of the Trial row was always sprayed with the left side of the sprayer.

FIGURE 2.2 Spraying plan for single-sided (SS) and double-sided (DS) spraying.



To confirm that inadequate mixing or rapid breakdown of the Helios dye was not occurring samples of spray solution containing 3.0 ml Helios per 100L were therefore collected from the spray nozzles 1, 2, 3, 4, 5 and 8.75 minutes after mixing. The results are given in FIGURE 2.3.

FIGURE 2.3 Spray dye concentration at nozzle immediately after tank mixing at 3.0 ml / 100L using a standard low profile airblast sprayer, SS SF45 hf.



This showed that it took about 3-4 minutes for full strength dye solution (>98% full strength) to arrive at the nozzles after spraying with water only. These results show that after 1 minute the concentration was extremely stable, varying by less than 2.7%. This would equate to a distance of 58 metres sprayed at 3.5 kph. This test was not repeated for each sprayer but the nozzle check and spraying of the first guard row took at least 4 minutes ensuring that full mixing had occurred before trial rows were sprayed.

2.4 Helios dye recovery procedure

Leaf samples were analysed for Helios residues by Glenn Geitz at QDPI Gatton. The procedure used is that developed by QDPI over several years. The procedure was as follows:

1. Take out leaves from paper bag and place 10 leaves in glass jar (# on lid etc).
2. Place each leaf into Licor 3000 UQ Leaf Area Meter (LAM).
3. Record leaf area (TOTAL LEAF AREA) [2].
4. Place leaves back into jar.
5. LAM total area recorded then reset.
6. Repeat each treatment.
7. Store leaves in paper bags inside large black plastic bags.
8. Place 10 leaves in glass jar.
9. Add solvent ethyldiglycol, 10 to 30 ml (SOLVENT VOLUME).
10. Put jars into Ball Mill Shaker for 2 mins.
11. Filter samples into 10 ml corvette.

[2] Leaves may crinkle slightly

12. Take fluorometer reading (calibrated using standards) once stable (INITIAL DISPLAY) using a Tuner Digital Fluorometer Model 450.
13. If INITIAL DISPLAY is too high (above 2000) then dilute.
14. Record DILUTION FACTOR.
15. Mix in vortex mixer.
16. Repeat Fluorometer reading (DILUTION READING).
17. DILUTION READING x DILUTION FACTOR = CALCULATED DISPLAY.
18. Helios conc. Nominally 500 g/L but seems to be 1000 g/L.
19. Store samples in fridge for 2 weeks.

Because some treatments were made with Yellow UV dye it was necessary to find out if the visible Yellow residues could increase the Helios fluorescent recovery. To check this samples of leaves from BO which showed visible Yellow dye were collected and analysed for fluorescence. The results did show a very low fluorescence equivalent to 0.00 to 0.04 $\mu L/cm^2$ Helios but this was insignificant compared with the fluorescence results of dipping in 3.0 ml/100L Helios of 4.3 – 10.2 $\mu L/cm^2$. From this we concluded that any Yellow UV dye residues would not significantly distort subsequent Helios treatments.

2.5 Droplet analysis

In order to gain further understanding of the Helios results several treatments were assessed using visual assessment of 25 x 75 mm water-sensitive paper (WSP) or image analysis of leaves or WSP. The procedure for visual assessment of WSP was to take counts of droplet numbers at 3 positions on the WSP using X3 magnification glasses. This is extremely difficult to do over a large area so areas of only $1/8^{th}$ of a cm were counted. All counts were carried out by the project leader. A comparison with counts by other team members using nil or X10 magnification varied widely. Image analysis of droplets was carried out by Glenn Geitz, QDPI Gatton, using the image analyser situated at QDPI Toowoomba.

2.6 Data analysis

Meaningful data analysis turned out to be a major difficulty. This report has been written with an emphasis on the "story" and the interpretation of the results rather than on the individual data or technology. The data showed high variability some causes of which we identified. The results highlighted the extreme complexity of the spraying process and it was therefore determined to concentrate on the patterns of coverage within the canopy rather than on the total recovery in any particular treatment. In order to permit valid comparisons between treatments all recoveries were corrected to a standard applied dose of 0.6 ml Helios /$100m^3$ of canopy. Eg. A recovery of 26.0 at an applied dose of 0.525 ml Helios/$100m^3$ gave a corrected recovery of 29.7 (26.0 x 0.600 / 0.525). However an unexplained difference in the concentration of the batches of Helios dye supplied by QDPI confounded the results.

The major assumption for comparing treatments was that the low variability of recovery across the canopy was the goal of application. However for some pests the target is generally the nut crop itself and its position within the canopy can vary. Anecdotal evidence suggests that the majority of crop in large trees is at the top. In this instance it may be that total recovery at TO, TI, MO and MI is the main criteria and should have extra weighting, whereas in smaller trees it may be recovery at BO, BI, MO and MI is more important. These factors made it very difficult to come up with a single number fully describing the coverage on the canopy. We therefore concentrated our analysis on trying to explain how different treatments shifted the distribution of spray.

A secondary goal was to minimise off-target losses, but for sprays below point-of-runoff these are extremely hard to quantify. Measurements of losses to the orchard floor were measured using sticks and the results are presented in Section 5.6.

Statistical analyses of treatments showed that many treatments did differ significantly. Statistical analyses were carried out with the assistance of staff at the University of the Sunshine Coast using the statistical package SPSS. However statistics alone did not present a clear picture as to how treatments differed. To present this information in an easily understandable form five main indices were used. These were:

(1) **The Penetration Index (PI)** being the total recovery of Inners (TI, MI, BI) divided by the total recovery of Outers (TO, MO, BO) where PI = (TI+MI+BI) / (TO+MO+BO) x 100. Being a ratio the PI will fall if the recovery of Outers increases, even for the same Inners recovery. It is a measure of the evenness of recovery across the horizontal axis of the tree.

(2) **The Height Index (HI)** being the total recovery of the Top (TO, TI) divided by the total recovery at the Bottom (BO, BI) where HI = (TO+TI) / (BO+BI) x 100. Being a ratio the HI will fall if the recovery of Bottom increases, even for the same Top recovery. It is a measure of the evenness of recovery across the vertical axis of the tree based on the two extremes but not the Middle.

(3) **The comparison of Top and Bottom with the Middle taken as a Standard of 100%.** Generally Tops were negative (ie. less than 100%) while most Bottoms were positive (ie. more than 100%). These results are generally presented as graphs.

(4) **The comparison of each sampling site with a standard $1/6^{th}$ of the total dye recovery, classified as the "optimum" dose.** This assumes that the aim of application is to deposit an equal dose on leaves on any part of the canopy. For example if the total recovery was 90, then the optimum for each sampling site would be $1/6^{th}$ or 15. A recovery of 10 in a particular sampling site would therefore be expressed as –33% (see TABLE 2.12 below). These results are generally presented as graphs.

TABLE 2.12 Comparing actual recovery with the "optimum".

Sampling site	**Actual recovery** example only	**Optimum recovery** Total / 6 (eg. **90/6**)	**Difference from Optimum (%)**
TI	5	15	-67%
TO	10	15	-33%
MI	10	15	-33%
MO	15	15	0
BI	20	15	33%
BO	30	15	100%
Total	**90**	15	*Sum is zero*

Finally,

(5) **The total percentage spray recovered in the body of the canopy**, discarding the recovery for the easiest (BO) and hardest (TI) positions to spray, ie. TO+MO+MI+BI / Total x 100.

2.7 The trial team

The original spraying project concept proposal accepted by the AMS was to be managed by QDPI. However staff changes at QDPI and priority changes by the AMS resulted in a new project proposal involving new consultants with QDPI laboratory backup. The team consisted of:

Dr Henry Drew — **Project Leader**
and Mrs Jenny Drew
HJ & JM Drew Consultants,
283 Hunchy Rd, Hunchy, QLD 4555.
Tel 07 5445 0032
Fax 07 5445 0940

Graham Betts — **Spray machinery specialist**
Ask GB,
PO Box 296, Drayton North, QLD 4350.
Tel 07 4613 4220
Fax 07 4613 4234

Glenn Geitz — **Dye analysis specialist**
QDPI,
Locked bag 7, Gatton, QLD 4343.
Tel 07 5462 2222
Fax 07 5462 3223

Chris Fuller — **Trial assistant**
Macadamia consultant
24 Gympie Rd, Kin Kin, QLD 4571
Tel 07 5485 4454

Bruce Henningsen
David Carr
Bruce Ensing
Glenn Kenny
Erin Lynch

Local spray machinery dealers or technical staff as required

Each trial involved the team meeting at the trial site for 3-4 days. Because of other work commitments it was difficult to reschedule trial days if the weather, machinery availability, mechanical breakdown or other disruption interfered in the trial. Time constraints also limited the flexibility to try unplanned treatments. On some occasions it was necessary to schedule subsequent trials without having the time to fully interpret the results of previous trials. Having a widely located team did create some difficulties but we were generally blessed with good weather and very few trials were adversely affected or needed to be repeated.

3. APPROPRIATE DILUTE SPRAY VOLUMES

3.1 T1 Looking for the point-of-runoff

3.1.1 T1 trial setup

The first trial (T1) was designed to determine the point-of-runoff (POR) of a mature macadamia tree and establish an industry recommendation for appropriate Dilute spray volumes on whoich to base EHVD. This is now required for interpretation of the new APVMA Model Label for tree crops concerning Concentrate spray rates.

The trial was carried out in Gowens 344 block, see Section 2.2 for details. The spray machine used was a new Silvan airblast sprayer with straightening vanes (designated SS SF45 hf) loaned free-of-charge by Silvan Pumps & Sprayers (Aust) P/L. This sprayer was selected as being representative of the industry standard, ie. a low-profile single-sided axial fan sprayer (TABLE 3.1). The tractor used was a Deutz DX7 loaned free-of-charge by Sahara Farms.

TABLE 3.1 T1Sprayer SS SF45 hf setup.

Tractor speed @ 2000 rpm	2.0 kph
Sprayer and tank size	Silvan SS SF45 hf with 2000 L tank
Fan size, pitch and gear	900 mm, 45° pitch and high fan gear
Average measured air inlet speed	14.0 m/sec
Estimated fan output *	71,600 m^3/hour
Conveyor	Single-sided, 2 passes per row
Estimated air volume per unit of canopy @ 2.0 kph	0.829 m^3 air / m^3 canopy each pass

The aim of the trial was to apply differing spray volumes while keeping all other variables constant. This was achieved by using one nozzle size and type and by varying the number of nozzles only. Using a constant nozzle size did restrict the maximum and minimum volumes tested. The nozzles and pressure selected for all treatments were Albuz ATR ceramic hollow cones, size 2.3 Green @ 15 bar. The details of the spray nozzle performance are given in Section 2.2.3.

The airflow from the machine was divided into 3 sections, being the top (T), middle (M) and bottom (B) thirds of the canopy. Nozzles were then allocated to the different sections of the tree in the approximate proportions T:M:B of 30:50:20%. This was achieved by using single, double or triple outlets where necessary. The proportions used were a compromise between the 60:30:10 recommended by Behncken (1983) in the 1980's and the 20:30:50 recommended by Broadley *et al.* (1993a & b) in the 1990's. We believed that the 30:50:20 ratio generally better copes with orchard variability, weather conditions and crop distribution factors. Any proportion selected will be a compromise strongly affected by tree age, variety and canopy structure & pruning.

In T1 five spray volumes spanning the expected POR were selected (TABLE 3.2).

TABLE 3.2 T1 Application volumes.

	MEDIUM VOLUME		HIGH VOLUME		VERY HIGH VOLUME
Treatment	**#1**	**#2**	**#3**	**#4**	**#5**
Volume/canopy	3.1 L/100m^3	5.0 L/100m^3	6.2 L/100m^3	7.0 L/100m^3	9.3 L/100m^3
Volume/ha	1655 L/ha	2690 L/ha	3310 L/ha	3724 L/ha	4965 L/ha

The weather conditions recorded at the start or end of each treatment are given in TABLE 3.3. The weather conditions were generally warm to very warm with little wind and an acceptable ΔT below 10.

TABLE 3.3 T1 Application conditions.

Treatment No.	Average wind speed (m/second)	Wind direction	Temperature (^{o}C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	0.6	NE	28.5	70%	4.5
#2	0.7	NE	30.0	65%	5.5
#3	0.7	E/NE	27.0	78%	3.0
#4	0.7	NE	30.5	60%	6.0
#5	0.5	E/NE	26.6	82%	2.5

The HELIOS dye used was mixed at a constant concentration of 6 ml / 100L. Tank samples were taken at the end of spraying and analysed to cross-check the mix concentration. Even at the highest rates HELIOS residues were not visible on the leaf. The HELIOS doses applied, based on field area and canopy volume, are given in TABLE 3.4.

TABLE 3.4 T1 HELIOS dosage applied.

	LOW VOLUME		HIGH VOLUME		VERY HIGH VOLUME
Treatment	**#1**	**#2**	**#3**	**#4**	**#5**
Volume/canopy	3.1 L/100m^3	5.0 L/100m^3	6.2 L/100m^3	7.0 L/100m^3	9.3 L/100m^3
Dye dose/canopy	0.186 ml/100m^3	0.303 ml/100m^3	0.372 ml/100m^3	0.419 ml/100m^3	0.559 ml/100m^3
Dye dose/ha	99 ml/ha	161 ml/ha	199 ml/ha	223 ml/ha	298 ml/ha

3.1.2 T1 results and discussion

For each treatment six trees were sampled at six different sample sites within the canopy as detailed in Section 2.1. Since different spray volumes were applied this meant that each treatment received a different dose. The results were therefore standardised or corrected to a standard HELIOS dose of 0.6 ml/100m^3 of canopy. Although 0.6 ml/100m^3 was lower than any actual treatment in this trial it was in the range of subsequent trials where the average HELIOS dose was only 30 ml / hectare.

The corrected results in TABLE 3.5 show that all treatments gave very low recovery in the top of the tree and in the inner section. However there were marked differences between the highest and lowest volumes. The biggest difference was in BI in the highest volume (FIGURE 3.1) and MO and TO in the lowest (FIGURE 3.2). A possible explanation for these differences is given in 3.1.4.

TABLE 3.5 T1 Corrected HELIOS recovery based on an applied dose of 0.6 ml Helios /100m^3.

Treatment	Application Volume L/100m^3	BO	BI	MO	MI	TO	TI
#1	3.1	65.4	36.7	72.8	35.1	68.6	22.7
#2	5.0	70.2	28.8	51.3	26.1	33.7	28.9
#3	6.2	43.7	44.2	43.2	28.3	24.9	17.6
#4	7.0	42.4	40.8	38.6	32.7	25.5	13.5
#5	9.3	57.4	50.2	45.2	30.0	28.3	19.0

FIGURE 3.1 T1 Dye recovery with the highest volume (9.3 L/100m^3).

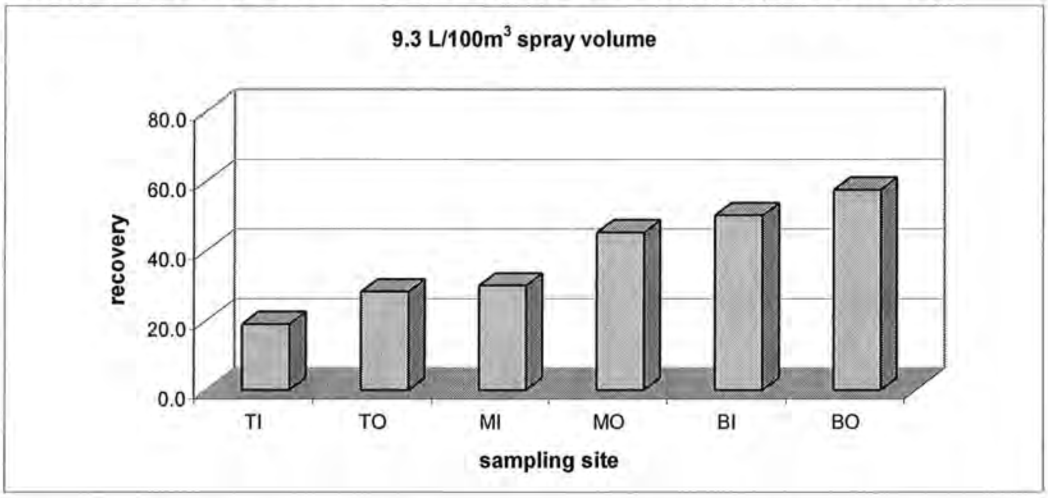
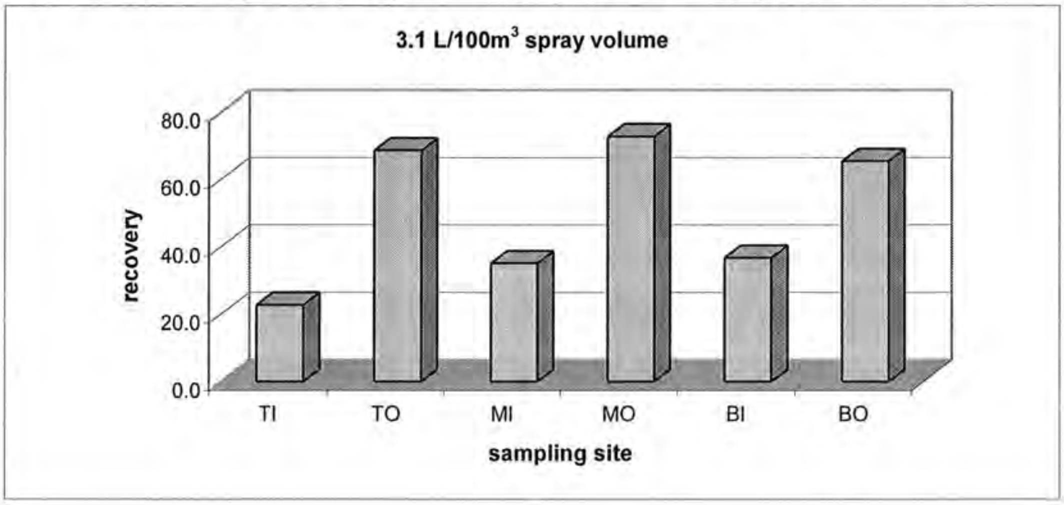


FIGURE 3.2 T1 Dye recovery with the lowest volume (3.1 L/100m^3).



Although there was little statistical difference between residues at different sampling sites within treatments there were obvious differences in penetration of the canopy and in height distribution as shown in FIGURES 3.1 and 3.2. In order to compare treatments two indices, PI and HI, were devised (see Section 2.6). These are presented in TABLE 3.6.

TABLE 3.6 T1 Corrected HELIOS coverage indices

Treatment	Volume $L/100m^3$	Total B:M:T	Penetration Index (PI)	Height Index (HI)
#1	3.1	301.1	46	89
#2	5.0	239.0	54	63
#3	6.2	201.8	81	48
#4	7.0	193.4	82	47
#5	9.3	230.0	76	44

These results, presented in TABLE 3.6 above and FIGURE 3.3 below, show that coverage inside the tree (PI) greatly improves at spray volumes over 6 $L/100m^3$. They also show that at spray volumes below 6 $L/100m^3$ there is greater uniformity between the top and the bottom (lower HI). It does not suggest there is actually more dye at the top – the HI actually increases because there is less dye at the bottom.

3.1.3 T9 Additional spray volumes

To extend the spray volumes tested in T1 an overlapping range of volumes were applied with another sprayer. The second sprayer was a grower's own machine of same brand and similar to SS SF45 hf, designated SS SF40 hf. The only difference was that SS SF40 hf did not have straightening vanes and had a 40° fan pitch not 45°. The air output of the second machine was slightly higher than the first despite having a lower fan pitch (TABLE 3.7).

TABLE 3.7 T9 Sprayer SS SF45 2 setup.

Tractor speed @ 2000 rpm	2.0 kph
Sprayer and tank size	SS SF40 hf with 2000 L tank
Fan size, pitch and gear	900 mm, 40° pitch and high fan gear
Average measured air inlet speed	14.5 m/sec
Estimated fan output	74,332 m^3/hour
Conveyor	Single-sided, 2 passes per row
Estimated air volume per unit of canopy @ 2.0 kph	0.845 m^3 air / m^3 canopy each pass

The extended range of volumes applied is given in TABLE 3.8.

TABLE 3.8 T9 Application volumes.

	LOW VOLUME			MEDIUM VOLUME
Treatment	#6	#7	#8	#9
Volume/canopy	1.8 $L/100m^3$	2.6 $L/100m^3$	4.0 $L/100m^3$	4.8 $L/100m^3$
Volume/ha	980 L/ha	1372 L/ha	2156 L/ha	2548 L/ha

The weather conditions recorded at the start or end of each treatment are given in TABLE 3.9. The weather conditions were generally warmer with a lower humidity for treatments #6 and #7. All treatments had little wind and an acceptable ΔT below 10.

TABLE 3.9 T9 Application conditions.

Treatment No.	Average wind speed (m/second)	Wind direction	Temperature (^{o}C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#6	NIL	NW	27.4	63	5.0
#7	1.2	NE	27.7	58	6.0
#8	1.0	S	23.4	75	3.0
#9	2.2	S/SE	21.0	83	2.0

The applied dose of Helios and its recovery are given in TABLES 3.10 and 3.11.

TABLE 3.10 T9 HELIOS dosage applied.

	LOW VOLUME			MEDIUM VOLUME
Treatment	**#6**	**#7**	**#8**	**#9**
Volume/canopy	1.8 L/100m^3	2.6 L/100m^3	4.0 L/100m^3	4.8 L/100m^3
Dye dose/canopy	1.103 ml/100m^3	1.544 ml/100m^3	2.426 ml/100m^3	2.867 ml/100m^3
Dye dose/ha	58.8 ml/ha	82.3 ml/ha	129.4 ml/ha	152.9 ml/ha

TABLE 3.11 T9 Corrected HELIOS recovery based on an applied dose of 0.6 ml Helios / 100m^3.

Treatment	Application Volume L/100m^3	BO	BI	MO	MI	TO	TI
#6	1.8	63.8	61.4	58.5	55.5	38.3	20.1
#7	2.6	76.3	41.1	91.7	27.5	51.3	24.5
#8	4.0	49.7	27.6	57.2	27.3	52.4	18.4
#9	4.8	71.7	29.4	52.4	26.7	36.7	33.6

FIGURE 3.3 shows the effect of spray volume on recovery at the Inner sites (TI, MI and BI). At BI recovery was highest at the very high and very low volumes. At MI the pattern was similar, but at TI it was reversed with highest recovery around 5 L/100m^3.

FIGURE 3.4 shows the effect of spray volume on recovery at the Outer sites (TO, MO and BO). At BO, the closest point to the sprayer, recovery was lowest at the very high volumes. This would appear to be due to excessive runoff. At TO there is a similar pattern but this is unlikely to be due to excess runoff but due to failure of the airstream to carry the large water volume effectively.

However the very differing recovery patterns at different sampling sites when using one sprayer, one speed, one nozzle type and one pressure suggested that the data analysis for differing treatments would be very complex.

FIGURE 3.3 T1 & T9 Effect of spray volume on recovery at TI, MI and BI.

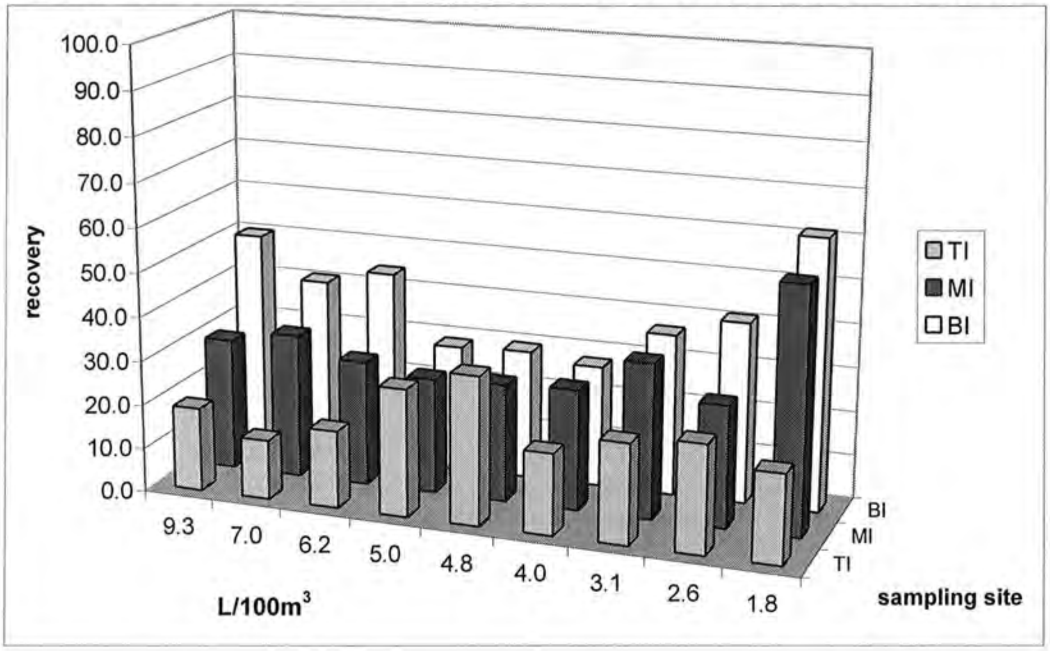
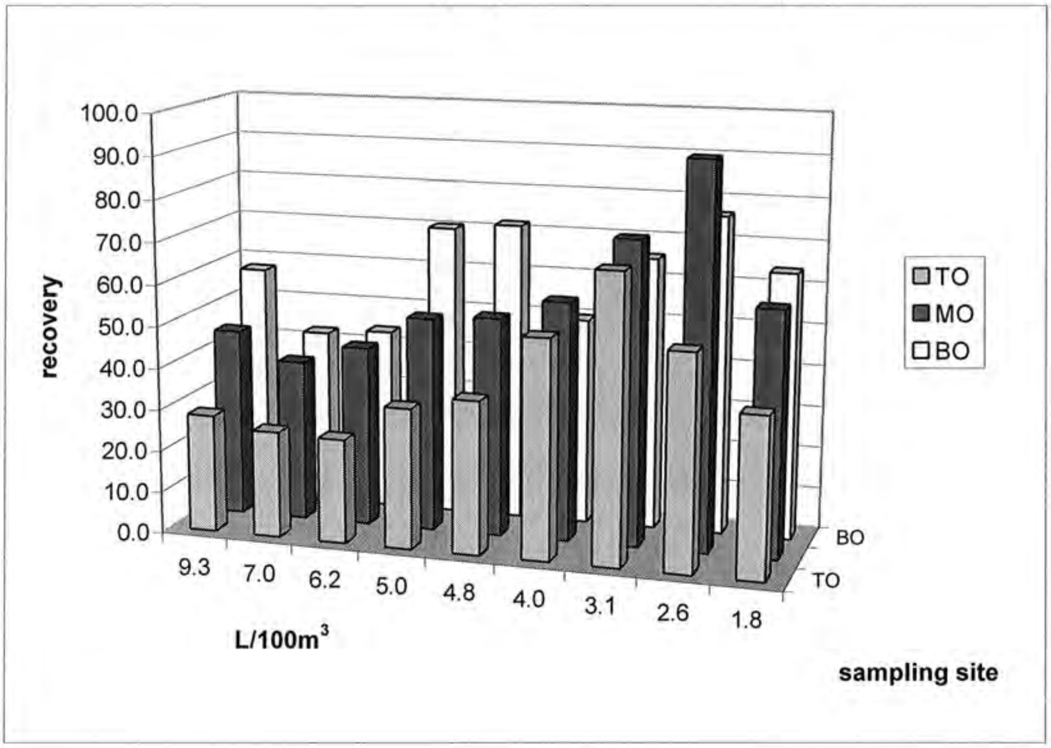


FIGURE 3.4 T1 & T9 Effect of spray volume on recovery at TO, MO and BO.



The additional PI and HI indices are given in TABLE 3.12 below.

TABLE 3.12 T9 Corrected HELIOS coverage indices

Treatment	Volume L/100m^3	Total B:M:T	Penetration Index (PI)	Height Index (HI)
#6	1.8	297.5	85	47
#7	2.6	312.4	42	65
#8	4.0	232.6	46	92
#9	4.8	250.4	56	70

FIGURES 3.5 and 3.6 both show how the PI increased at both very high and very low volumes. The HI did the reverse, being lowest at very high and very low volumes. Given the uniform droplet size applied the explanation for this had to be related to carriage of different volumes by air or to redistribution within the canopy.

FIGURE 3.5 T1 & T9 Combined Penetration Index (PI) and Height Index (HI).

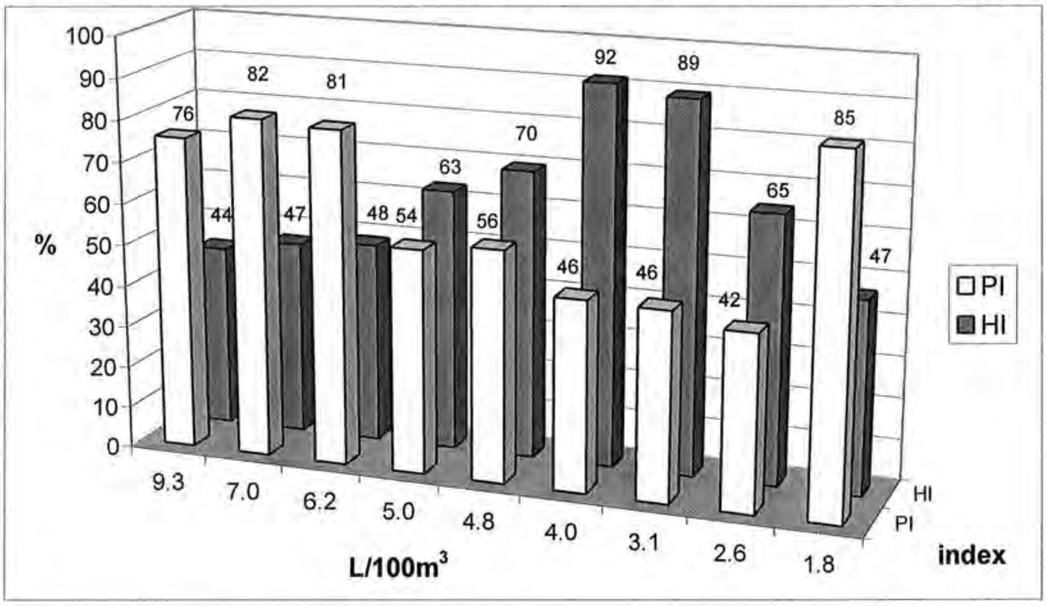
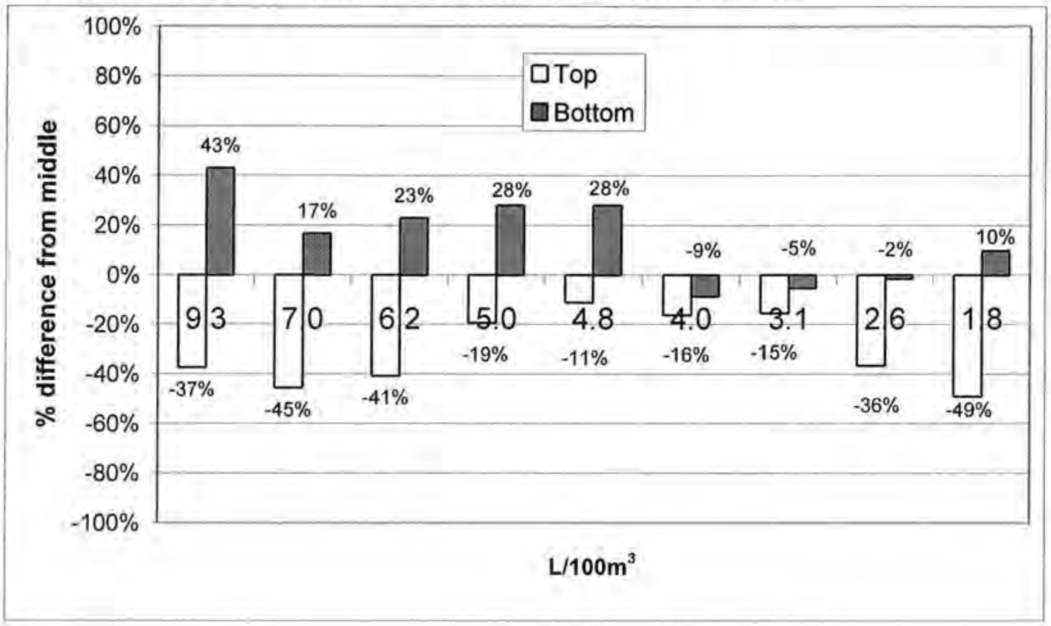


FIGURE 3.6 shows that the most uniform coverage from top to bottom was achieved at a spray volume of 3-4 L/100m^3. At this volume the top and bottom totals were very close to the total at the middle, within 16%. However these results do not fully indicate the differences in canopy penetration highlighted in FIGURES 3.3, 3.4 and 3.5.

FIGURE 3.6 T1 & T9 Combined % Difference from Middle.



3.1.4 Implications

One explanation of the results is as follows.
Droplets contributing to recovery reach their targets by six main routes, namely:

(1) directly from the sprayer in the fan airstream as the sprayer passes,
(2) falling under gravity after the sprayer has passed,
(3) drifting in the general air flow after the sprayer has passed,
(4) runoff down surfaces,
(5) dripping from surface to surface.
(6) droplet splatter

At low volumes below 6 $L/100m^3$ the first three routes predominate. However above 6L runoff begins across much of the canopy and routes (4), (5) and (6) increase in importance. These two routes redistribute dye to surfaces which cannot be accessed by routes (1) – (3). In layman's terms it begins to rain inside the canopy. Because this movement is downward it increases the dye recovery particularly at BI. Increasing BI increases PI and reduces HI. BO does not increase so much because at these volumes it is likely to have reached runoff already.

Below 6 $L/100m^3$ the coverage of the outside of the tree rises. This is presumably because the leaf can actually hold more water/dye as droplets than it can once droplets coalesce. This phenomenon is well documented (Matthews, 1979). Inside the canopy there is no rain so droplets are deposited by routes (1) – (3). It is not raining in the canopy so there is no increase in MO or, more particularly, BO. The data suggest that 6 $L/100m^3$ is a better estimate of POR in macadamias than the figure of 7.5 L or higher used in some other crops. Returning to the real life situation of the trial block at Sahara Farms the new estimate of POR can now be given as follows:

TABLE 3.13 Estimation of Dilute spray volume for Sahara Farms Road Block.

SAHARA FARMS Mountain Block	Estimated Dilute volume L/100m^3	Calculated L/tree	Calculated L/hectare
NEW Estimate of POR	6.00	13.0	3211

Whatever volume it is decided to use for the Dilute/Concentrate conversion it must be able to be justified. The NRA Model Label allows the growers to determine the appropriate Dilute spray volume based on Practical experience, Expert advice, Industry guidelines, Hand spraying or Estimates of Plant Row Volume or Unit Canopy Row (eg. Furness *et al.*, 1998).

The point at which the runoff within the canopy makes a difference appears to be around 6 L/100m^3 of canopy.

THIS IS THE RECOMMENDED SPRAY VOLUME ONLY FOR DILUTE SPRAYING.

If this volume is evenly spread across the sprayed canopy there is likely to be increased coverage in the inner sampling sites through vertical redistribution, or raining. This may be what is required to achieve highly effective coverage of nuts for varieties like A16 and A38 which carry a lot of their crop in heavy bunches in the middle of the canopy. So with a block of A16's with canopy volumes of 80 m^3 (4 x 4 x 5 m) you would need to apply 4.8 L/tree (6.0 x 80/100) to achieve internal runoff. For this application the Dilute spray rate per 100L should be used.

THE DILUTE VOLUME IS NOT THE RECOMMENDED VOLUME FOR OPTIMUM EFFECTIVENESS. IT IS SIMPLY THE DILUTE SPRAY BENCHMARK BY WHICH TO CALCULATE CONCENTRATE SPRAY RATES.

If you were confident of achieving good coverage inside the canopy of those same A16's with a lower volume spray of, say, 2.4 L/tree, then you should use the Concentrate spraying rate of 2X (4.8/2.4), or 2 times the Dilute rate. The essential factor to establish the Dilute/Concentrate rate conversion is the appropriate Dilute spray volume. For example, the new Bulldock 25 EC label permits use of Concentrate sprays up to 5X. This means, theoretically, that you could go as low as 1.2 L/100m^3 (6/5) or 1 L/tree in spray volume and increase the spray concentration to 5X.

4. COMPARING TECHNOLOGIES

4.1 General

4.1.1 Introduction

The following trials were a series looking at different technologies. The aim was not to compare brands or suppliers but to try and get a better understanding of the underlying factors affecting the performance of the technology. To do this we concentrated on two main parameters, namely:

- Tractor speed in the range 2-5 kph. Changing speed also changes the volume of air/unit canopy.
- Spray volume in the range 1-4 L/100m^3 of canopy. This range can be considered low volume, below point-of-runoff, and appropriate for Concentrate sprays as per the NRA Model Label for tree crops.

Other parameters were kept the same, or as close as possible, between treatments, eg:

- Spray pressure of 15 bar or 1500 KPa (218 psi).
- Dose of HELIOS dye at 30-35 ml/hectare. All results were Standardised to an applied dose of 0.6 ml Helios applied /100m^3 of canopy.
- A single jet type (Albuz ATR ceramic hollow cone), using sizes Green, Red or Orange with similar VMD and droplet size range (see Section 2.2.3).

Ten different sprayers or fan components were assessed. These included:

1. One single-sided (SS) single fan (SF) low-profile sprayer with fan blades at 45^o pitch (45) and high fan gear, designated SS SF45 hf.
2. One single-sided (SS) single fan (SF) low-profile sprayer with fan blades at 40^o pitch (40), designated SS SF40 high fan gear (hf) or low (lf).
3. One double-sided (DS) single fan (SF) low-profile sprayer with fan blades at 35^o pitch (35), designated DS SF35.
4. One double-sided (DS) double fan (DF) low-profile sprayer with fan blades at 45^o pitch (35), designated DS DF45.
5. One double-sided (DS) single fan (SF) low-profile sprayer with fan blades at 45^o pitch (45) and with modified inlets and outlets (X), designated DS SF45 X hf or lf.
6. Two double-sided (DS) centrifugal fan (CF) airshear sprayers with tower (T) conveyors, designated DS CF T1 and DS CF T2.
7. One single-sided (SS) straight through tower (T) fan (F), designated SS 1TF.
8. One double-sided (DS) single fan (SF) low-profile sprayer with fan blades at 35^o pitch (35) PLUS two tower (T) fans (F, one per side), designated DS SF35 + 2TF.
9. One double-sided (DS) sprayer with eight straight through tower (T) fans (F, 4 per side), designated DS 8TF @ 1500 or 1800 rpm.

4.2 Air volumes

Air volume output of each sprayer was measured using average air inlet speed using the method and formulae of Battaglia *et al.* (c.1997). Air inlet velocity was measured at 20 positions as shown in APPENDIX A.

The formula is: $A = E \times I \times V \times 3600$,
where

A = Air volume in m^3/hour
E = Entrainment factor, a factor of 2 was used for all sprayers.
I = effective Inlet area in m^2
V = average air inlet Velocity in m/second

It was assumed that the output per side of double-sided sprayers was half the total air output. Of course this is unlikely to be the case. The effects of this variation will depend on the row spray pattern used. If the sprayer sprays adjacent rows then each row gets sprayed by either two left sides or two right sides. There are more complicated spray patterns that can reduce this but still one third of rows would be sprayed by the same side of the sprayer. Of course across the whole orchard there would be the same number of left- and right-sided rows and it is probably not worth the greater risk of missed rows to attempt a more complex pattern.

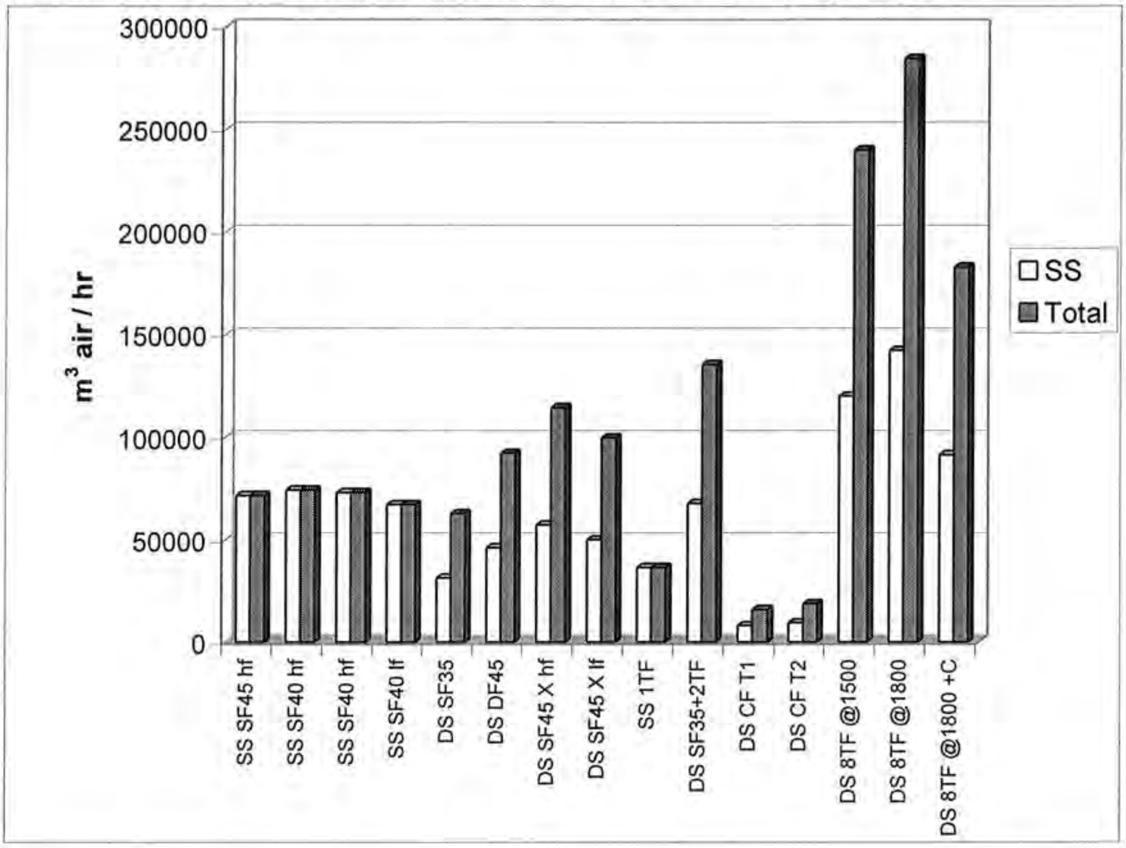
Individual fan characteristics and output calculations are given in APPENDIX E. A summary of the total output and single-side output of each sprayer are shown in TABLE 4.1 and FIGURE 4.1.

TABLE 4.1 Sprayer air volume calculations

	Average air inlet speed (m/sec)	**Air volume per side (m^3/hr)**	**Total air volume (m^3/hr)**
SS SF45 hf – "Standard"	**14.0**	**71611**	**71611**
SS SF40 hf	14.5	74332	74332
SS SF40 lf	13.1	67119	67119
DS SF35	13.0	31353	62707
DS DF45	*	46106	92213
DS SF45X hf	16.6	57193	114387
DS SF45 X lf	14.5	49881	99762
DS CF T1	27.1	7900	15800
DS CF T2	*	9338	18675
SS 1TF	23.6	36313	36313
DS SF35+2TF	*	67666	135333
DS 8TF @1500	14.6	119941	239882
DS 8TF @1800	17.3	142173	284346
DS 8TF @1800 +C	11.1	91397	182794

* where sprayers had more than one air inlet these were recorded separately

FIGURE 4.1 Sprayer Total air volume and single-sided (SS) output.

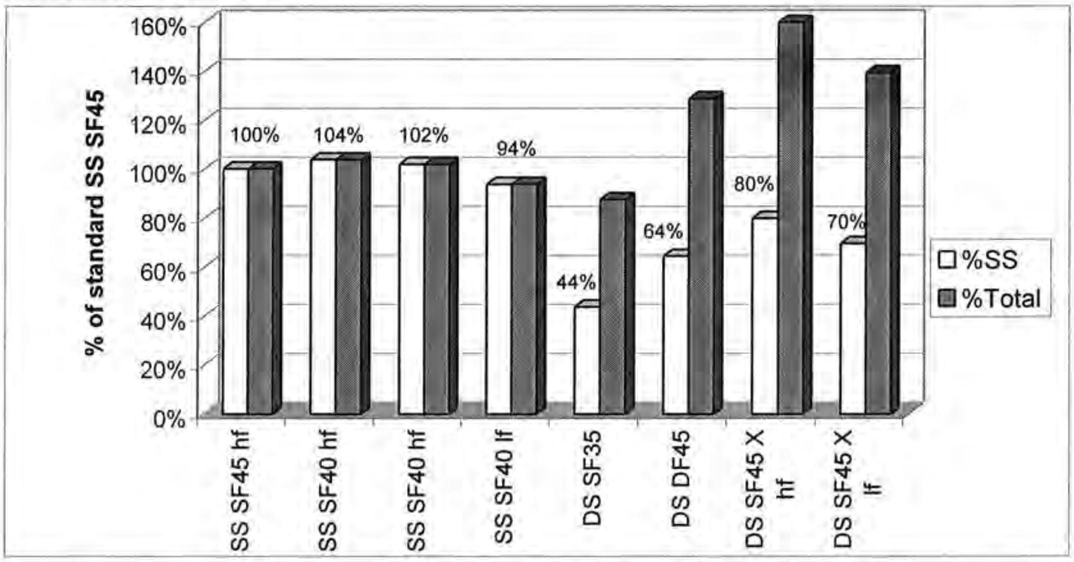


SS = single-sided sprayer	DS = double-sided sprayer
SF = single axial fan	DF = double axial fans
35-45 = 35°, 40° or 45° axial fan pitch	CF = centrifugal fan
T = tower or tower conveyor	1TF = one tower fan
hf = high fan gear	lf = low fan gear

As can be seen in FIGURE 4.2 the output of the two SS SF sprayers with 45° or 40° pitch fans were very similar. The single-sided output of SS SF45 hf was 71611 m^3/hr, which can be used as a standard for comparison with other sprayers. Reducing the fan gear from High (hf) to Low (lf) reduced output by approximately 6% only, possibly suggesting that back pressure within the fan conveyor at high fan speed was reducing output. It was also found that at certain positions on the air inlet the air was actually coming out! The most consistent "dead" air position, in some instances with a negative inlet speed, was close to the 2 o'clock position near the centre fan axis.

Reducing the fan pitch to 35° (SF35) reduced total output to only 88% compared with the 45° pitch (SF45) as shown in FIGURE 4.2. Of course changing from the single-sided conveyor (SS SF45) to double-sided (DS SF35) further reduced the output per side to only 44%.

FIGURE 4.2 Relative air volumes for low profile axial fan sprayers compared with Standard SS SF45 hf.



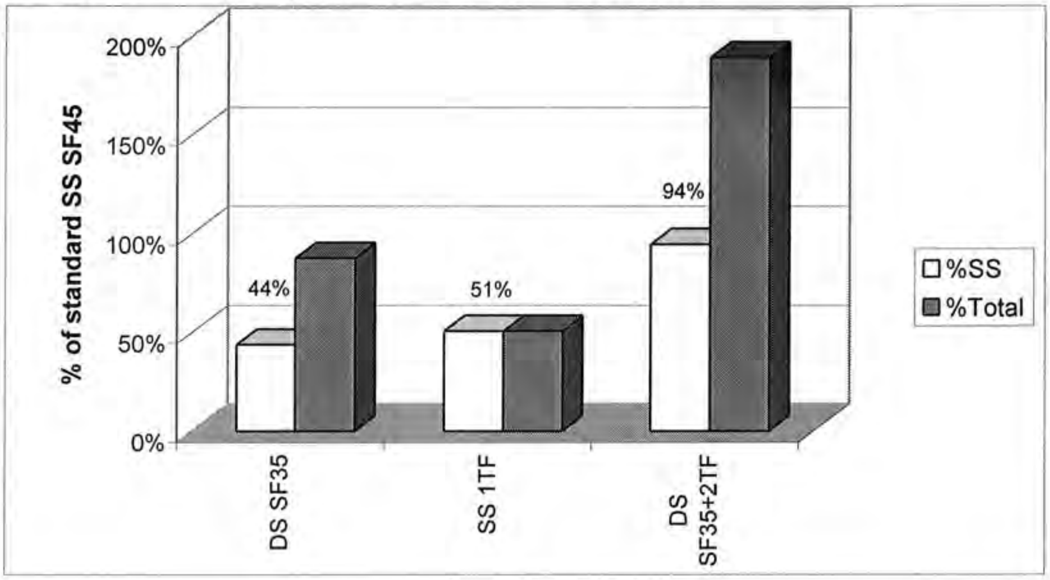
To get round the reduction in air volume in the switch to double-sided spraying various attempts have been made by manufacturers to increase the air volume. This change has been driven by the assumption that spraying in large tree crops is achieved by canopy air displacement, hence bigger trees need more air.

Some manufacturers have changed from a single fan setup to a double fan (DS DF45), others have simply opted for larger fans (up to 1000 mm). Changing to a double fan increased total output to 128% but this was still only 64% of the SS SF45 hf single-sided output (FIGURE 4.2). Interestingly one manufacture claimed to have designed a more efficient double-sided conveyor with greater output even with a standard single fan (DS SF45 X). This machine had a measured total output of 160% and single-sided output of 80%. It would seem that the claims for this machine are valid, suggesting that great improvements in inlet and conveyor design for low profile axial fan sprayers can be made. This particular sprayer did not exhibit any "dead" air zones or backpressure on the inlet.

However all these low profile axial fan machines have one major drawback. In all of them the air is drawn into the sprayer from front or back and then turned at 90^{o} before exiting. This is likely to be highly inefficient. This was highlighted by the tests on two types of straight through fans. One of these is available as an add-on with a hydraulic motor and standard hydraulic nozzles (SS 1TF) and can be fitted to a simple tower attached to a low-profile sprayer.

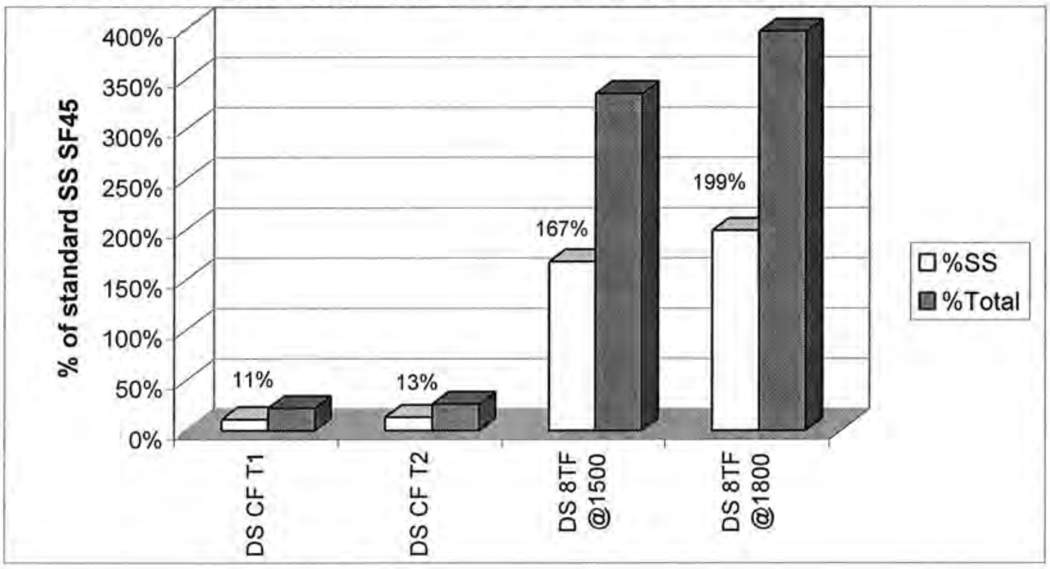
For their small effective inlet area these straight through fan sprayers generate relatively high air inlet velocities (see TABLE 4.1) and consequently high air outputs. The single straight through head with a 500 mm fan produced 50% of the air of the SS SF45 hf with a 900mm fan while using perhaps only 4 kW (5 hp) of the power (FIGURE 4.3). For an existing single-sided sprayer (SS SF45) addition of only one head on a farm-built tower could increase total air volume by 50% and air delivery to the top portions of the tree by substantially more. These straight through sprayers show great promise.

FIGURE 4.3 Relative air volumes for a double-sided low profile axial fan sprayer with tower fans compared with Standard SS SF45.



The second type of straight through fan was found on a dedicated CDA type tower sprayer with 4 heads per side (DS 8TF). The purpose built CDA sprayer produced a massive 398% air compared with SS SF45 hf, and even 195% per side. We had high expectations for this machine also. In trial T4 and T5 the CDA sprayer and an airshear sprayer were compared with very surprising results. Air output for these sprayers compared with SS SF45 hf is shown in FIGURE 4.4.

FIGURE 4.4 Relative air volumes for two airshear and a CDA spinning disc sprayer at 1500 or 1800 rpm compared with Standard SS SF45 hf.



According to the canopy air displacement model, the air from the sprayer displaces the air from within the canopy and replaces it with spray-laden air. To achieve this would require at least one m^3 of air per m^3 of canopy. However as shown in TABLE 4.2 below, even with an entrainment factor of 2, none of the low profile sprayers tested in Gowens 344 came close to this volume, even at only 2.0 kph. The performance of the airshear sprayer DS CF2 in T12, with an air displacement of only 0.108 m^3 air/m^3 canopy, confirmed the importance of the drift process vs canopy air displacement.

TABLE 4.2. Air output (m^3) per unit of canopy (m^3) per pass, Gowens 344.

Gear	L1	L3	L4
kph @ 2000 rpm	**2.0**	**3.4**	**4.8**
SS SF45 hf	0.829	0.488	0.345
DS SF35+2TF	0.783	0.461	0.326
DS DF45	0.534	0.314	0.222
SS SF40 hf (1)	0.860	0.506	0.358
SS SF40 hf (2)	0.845	0.497	0.352
SS SF40 lf	0.777	0.457	0.324
DS SF45 X hf	0.662	0.389	0.276
DS SF45 X lf	0.577	0.340	0.241
DS CF T2	0.108	0.064	0.045

The comparable figures for sprayers tested in Arbuckles 344 are given in TABLE 4.3. The CDA spinning disc sprayer, DS 8TF, did theoretically produce enough air for displacement to occur (>1) at low speed up to 3.8 kph. The airshear sprayer, DS CF1 would likely produce negligible air displacement.

TABLE 4.3 Air output per pass per unit m^3 of canopy, Arbuckles 344.

Gear	B1	C1	C3	A4	A4	B2	C1
kph @ rpm	**2.3**	**3.8**	**5.4**	**2.0**	**2.2**	**3.8**	**5.2**
DS CF T1 @ 2000	-	-	-	-	0.128	0.074	0.054
DS 8TF @ 1500	1.862	1.127	0.793	-	-	-	-
DS 8TF @ 1800	-	-	-	2.539	-	-	-
DS 8TF+C @ 1800	-	-	-	1.632	-	-	-

4.2 T2 Standard low-profile single-sided airblast sprayer (SS SF45 hf)

The trial was carried out in two blocks of mature cultivar 344, at Sahara Farms and in Terry Morgan's adjoining block, at Glasshouse Mountains. Characteristics of the Gowens 344 and Morgans 344 trial blocks are given in Section 2.2.1. The trial matrix is given in TABLE 4.4 below.

TABLE 4.4 T2 trial plan matrix.

	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
	x	#5 Morgans 344 2.0 kph 2.3 L/100m^3 1079 L/ha	x	**SLOW SPEED**
Treatment **Trial block** **Speed** **Volume/canopy** **Volume/ha**	#1 Gowens 344 3.4 kph 1.0 L/100m^3 534 L/ha	#2 Gowens 344 3.4 kph 2.0 L/100m^3 1048 L/ha	#3 Gowens 344 3.4 kph 4.0 L/100m^3 2124 L/ha	**MEDIUM SPEED**
	x	#4 Morgans 344 4.8 kph 2.2 L/100m^3 1047 L/ha	x	**FAST SPEED**

The spray machine used was a low-profile single 900 mm axial fan airblast with straightening vanes and single-sided conveyor (SS SF45 hf). As in Trial 1 this sprayer was selected as being representative of the industry "Standard" (TABLE 4.5 and FIGURE 4.5).

TABLE 4.5 T2 Sprayer setup.

Sprayer and tank size	Silvan SS SF45 hf with 2000 L tank
Fan size, pitch and gear	900 mm, 45^{o} fan pitch with high fan gear
Average measured air inlet speed	14.0 m/sec
Estimated fan output *	71,611 m^3/hr
Conveyor	Single-sided

FIGURE 4.5 The SS SF45 hf sprayer in action in cv. 246.

All treatments were applied at a pressure of 15 bar using Orange, Red or Green Albuz ATR nozzles as shown in TABLE 4.6.

TABLE 4.6 Treatments, spray volumes, nozzles, pressures and flow rates.

	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
	x	#5 2.3 L/100m^3 1 Rd, 8 Or 16.0 L/min	x	**SLOW SPEED**
Treatment Volume/canopy Nozzles Flow/side	#1 1.0 L/100m^3 8 Or 13.6 L/min	#2 2.0 L/100m^3 2 Gr, 5 Rd, 5 Or 26.7 L/min	#3 4.0 L/100m^3 9 Gr, 11 Rd 54.1 L/min	**MEDIUM SPEED**
	x	#4 2.2 L/100m^3 10 Rd, 8 Or 37.7 L/min	x	**FAST SPEED**

Application conditions, as shown in TABLE 4.7, were cool and very humid with a light E-N breeze. Showers were all around.

TABLE 4.7 T2 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (^{o}C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	1.0	N	21.6	74	3.5
#2	0.6	E	22.1	78	3.0
#3	0.6	E	22.4	80 *	2.5
#4	0.3	N/E	22.0	93	1.0
#5	0.2	E	18.7	100	0

* very light drizzle on samples 3-6

The applied dose of Helios and subsequent recoveries are given in TABLES 4.8 and 4.9.

TABLE 4.8 T2 HELIOS dosage applied.

Treatment No.	Calculated Spray volume (L/100m^3)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose (ml/100m^3)
#1	1.0	6.0	32.0	0.601
#2	2.0	3.0	31.4	0.590
#3	4.0	1.5	31.9	0.597
#4	2.2	3.0	31.4	0.673
#5	2.3	3.0	32.4	0.694

TABLE 4.9 T2 Corrected HELIOS recovery based on an applied dose of 0.6 ml Helios/100m^3

Treatment	BO	BI	MO	MI	TO	TI
#1	15.5	11.2	11.2	9.4	7.3	3.4
#2	11.0	4.6	7.4	3.2	6.3	2.1
#3	12.9	10.0	12.7	6.3	7.0	5.5
#4	20.0	4.5	14.8	4.1	10.6	5.8
#5	13.8	5.0	10.4	5.8	9.4	4.6

The recovery indices, PI and HI, showed a confusing picture (TABLE 4.10).

TABLE 4.10 T2 Corrected HELIOS coverage indices.

Treatment	Volume (L/100m^3)	Total B:M:T (ng/cm^2)	PI	HI
#1	1.0	57.9	71	40
#2	2.0	34.6	40	54
#3	4.0	54.4	67	54
#4	2.2	59.7	32	67
#5	2.3	49.0	46	74

PI was high in treatments #1 (1.0 L/100m^3) and #3 (4.0 L/100m^3) but lower in all the treatments at 2.0 L/100m^3. HI was high in treatments #4 (4.8 kph) and #5 (2.0 kph) and lowest in #1. This corresponded with the lowest and highest ΔT, suggesting that evaporation of droplets could be a factor in HI. Treatments #4 and #5 were also applied in Morgans 344 which had a smaller canopy volume per hectare of about 47,000 m^3 compared with 53,000 m^3 for Gowens 344.

FIGURE 4.6 shows the effect of tractor speed on recovery at medium volume (2.0-2.4 L/100m^3). The poor penetration of the canopy is evident, even at BI at 2.0 kph single-sided, throwing doubt on the air displacement concept. The results were consistent with T1 using the same sprayer.

FIGURE 4.6 T2 Effect of speed on recovery at medium volume (2.0-2.4 L/100m^3).

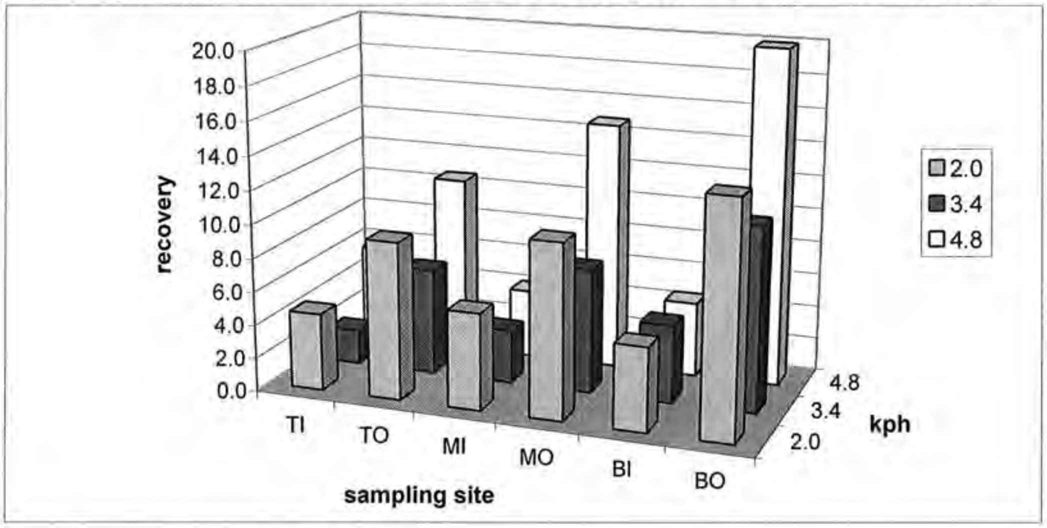
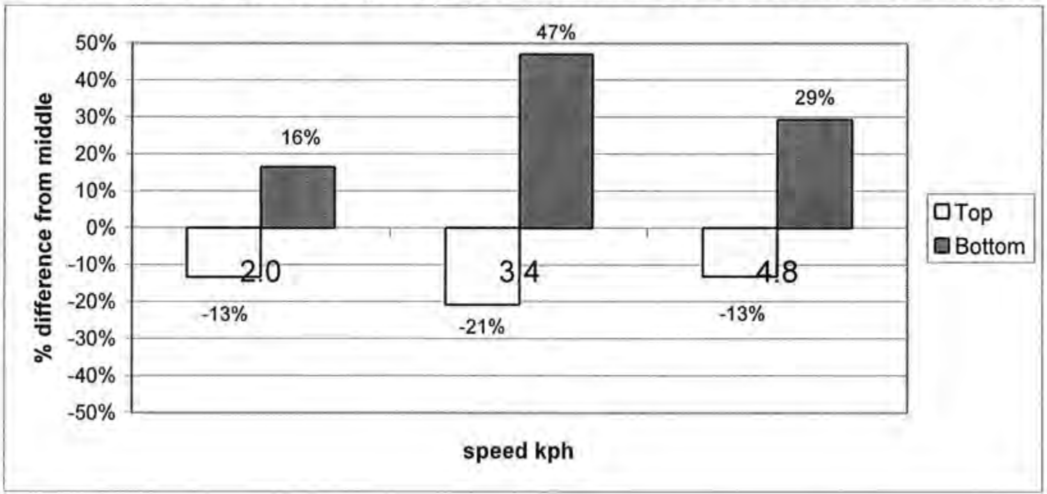


FIGURE 4.7, however, does indicate that more uniform coverage is achieved from top to bottom at the lowest speed of 2.0 kph, with the top being 13% lower than middle and the bottom being only 16% higher.

FIGURE 4.7 T2 Effect of speed on % Difference from Middle at medium volume.



At medium volume PI fell as speed increased from 46 to 40 to 32% (FIGURE 4.8), but HI was relatively constant. However the results could have been confused by the use of two different, but very similar blocks, for this comparison. Morgans 344 were more variable in canopy shape than Gowens 344, which had been more recently pruned.

FIGURE 4.8 T2 Effect of speed on PI and HI at medium volume.

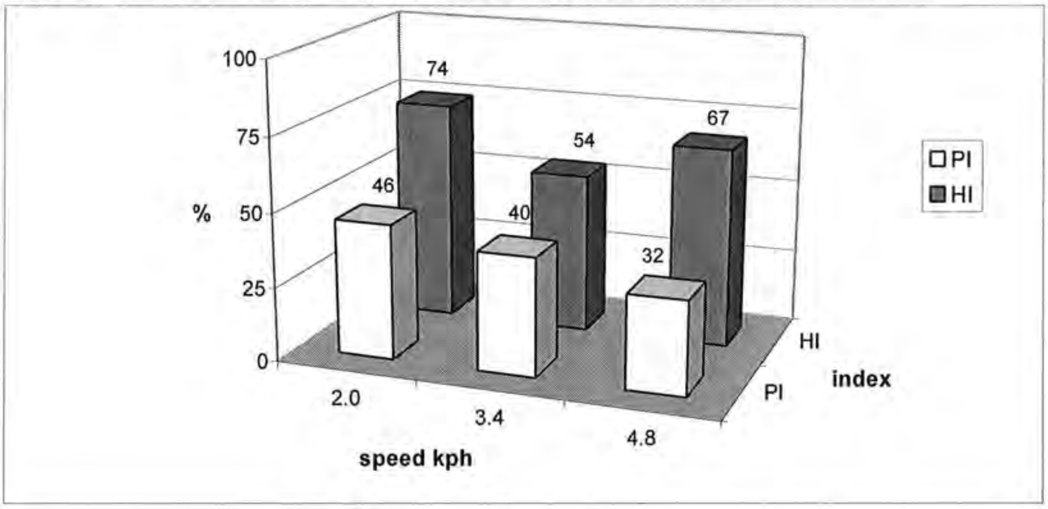


FIGURE 4.9 shows the effect of change in spray volume on recovery at medium speed (3.4 kph). No consistent effects of spray volume were apparent with the highest and lowest volumes having very similar PI. The HI at the lowest volume was lower due to the relatively high recovery at BI. HI was only 40-50% in all treatments (FIGURE 4.10). PI for the 2.0 L/100m^3 treatment was much lower than at 1.0 or 4.0 L/100m^3 at only 40%.

FIGURE 4.9 T2 Effect of volume on recovery at medium speed (3.4 kph).

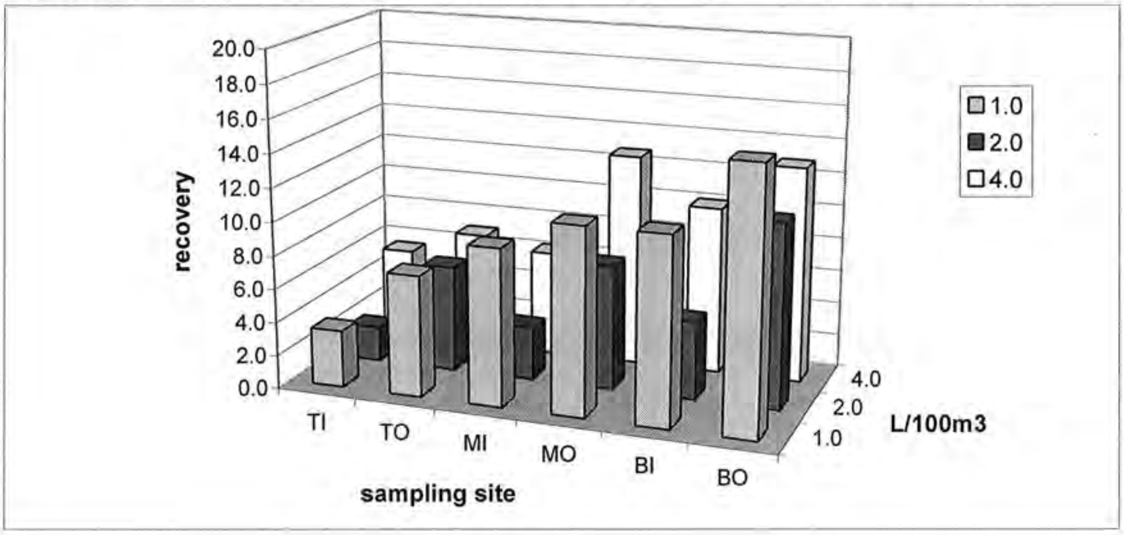
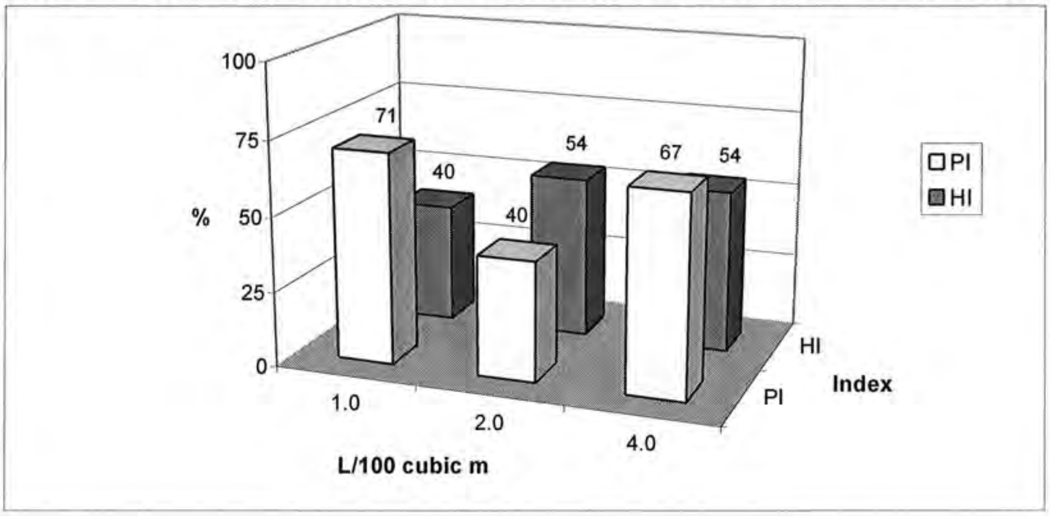
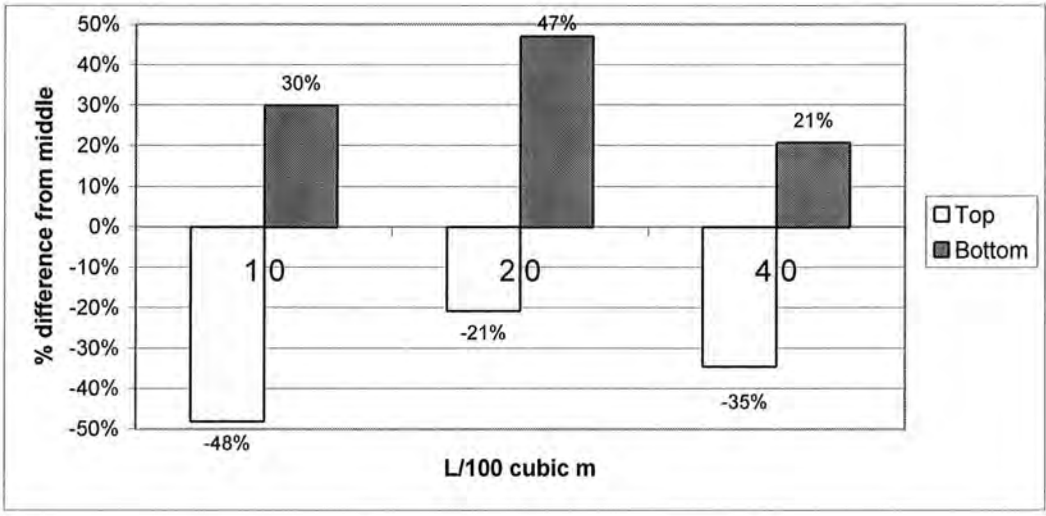


FIGURE 4.10 T2 Effect of volume on PI and HI at medium speed (3.4 kph).



At medium speed all treatments resulted in underdosing of the top and overdosing of the bottom as shown in FIGURE 4.11.

FIGURE 4.11 T2 Effect of volume on % Difference from Middle at medium speed (3.4 kph).



4.3 T3 Low-profile double-sided airblast with single tower fan per side (DS SF35+2TF)

The trial was carried out in block of mature cultivar 344 at Sahara Farms, Glasshouse Mountains. Characteristics of the Gowens 344 trial block are given in Section 2.2.1.

TABLE 4.11 T3 trial plan matrix.

	LOW VOLUME	**MEDIUM VOLUME**	**HIGH VOLUME**	
	x	**#9** Gowens 2.0 kph 2.0 L/100m^3 1079 L/ha	x	**SLOW SPEED**
Treatment **Trial block** **Speed** **Volume/canopy** **Volume/ha**	**#6** Gowens 3.4 kph 1.0 L/100m^3 534 L/ha	**#7** Gowens 3.4 kph 2.0 L/100m^3 1048 L/ha **#11** 1.7 L/100m^3 907 L/ha	**#8** Gowens 3.4 kph 4.0 L/100m^3 2124 L/ha	**MEDIUM SPEED**
	x	**#10** Gowens 4.8 kph 2.0 L/100m^3 1047 L/ha	x	**FAST SPEED**

The spray machine used was a low-profile single 920 mm 8-bladed axial fan airblast with straightening vanes. Attached was a simple tower with a single 500 mm 6-bladed hydraulically driven fan at 4.5 metres (DS SF35+2FT). See FIGURE 4.12. The sprayer was double-sided with 10 nozzles per side at the bottom and 8 nozzles per head on the tower. Sprayer setup is given in TABLE 4.12.

TABLE 4.12 T3 Sprayer setup.

Sprayer and tank size	Croplands DS SF35+2FT with 1500 L tank
Fan size, pitch and gear	920 mm axial, 35^o pitch, High speed fan gear + 320 mm tower fan
Average measured air inlet speed	13.0 +23.6 m/sec
Estimated fan output *	62,707 + 72,626 = 135,333 m^3/hr
Conveyor	Double-sided

All treatments with Albuz ATR nozzles were applied at a pressure of 15 bar using Orange, Red or Green sizes as shown in TABLE 4.6.

FIGURE 4.12 The DS SF35+2FT sprayer in action.

At the suggestion of Graham Betts the Albuz ATR ceramic hollow cones were compared with Teejet TXVK Gray jets in one treatment, #11. This was based on very even droplet size data supplied by QDPI. The treatment with the Teejet TXVK nozzles was applied at 20 bar.

TABLE 4.13 Treatments, spray volumes, nozzles, pressures and flow rates.

	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
	x	#9 2.0 L/100m^3 1 Rd, 8 Or 16.0 L/min	x	**SLOW SPEED**
Treatment Volume/canopy Nozzles Flow/side	#6 1.0 L/100m^3 8 Or 13.6 L/min	#7 2.0 L/100m^3 2 Gr, 5 Rd, 5 Or 26.7 L/min #11 1.7 L/100m^3 20 TXVK Grey 23.1 L/min	#8 4.0 L/100m^3 9 Gr, 11 Rd 54.1 L/min	**MEDIUM SPEED**
	x	#10 2.0 L/100m^3 10 Rd, 8 Or 37.7 L/min	x	**FAST SPEED**

Application conditions (TABLE 4.14) were warm and mild except for #1 which was cold with a high humidity and very low ΔT.

TABLE 4.14 T3 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (°C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#6	0.5	S	19.4	90	1.0
#7	0.3	N	25.6	70	4.0
#8	0.9	N	25.1	74	3.5
#9	0.5	N	23.7	77	3.0
#10	1.1	N	25.0	73	3.5
#11	0.7	N	26.6	62	5.5

The rates and dose of HELIOS used are given in TABLE 4.15. The recovery data and PI and HI are given in TABLES 4.16 and 4.17, respectively. Unfortunately the recovery data for treatments #9 and #10 was corrupted in the lab and meaningful recovery data could not be gathered.

TABLE 4.15 T3 HELIOS dosage applied

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#6	1.0	6.0	32.0	0.601
#7	2.0	2.8*	29.3	0.550
#8	4.0	1.5	31.9	0.597
#9	2.0	3.0	32.4	0.607
#10	2.0	3.0	31.4	0.589
#11	1.7	3.0	27.2	0.510

* The tank sample for #7 showed that the Helios concentration was only 2.8 ml/100L, lower than the intended 3.0.

TABLE 4.16 Corrected HELIOS recovery (ng/cm^2 leaf) based on an applied dose of $0.6\ ml/100m^3$

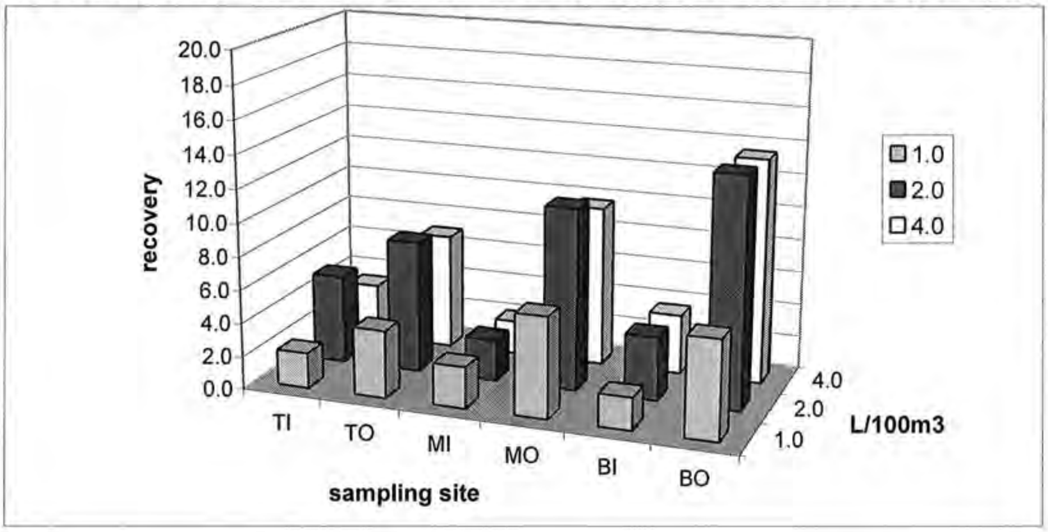
Treatment	BO	BI	MO	MI	TO	TI
#6	5.9	2.0	6.0	2.5	4.1	2.1
#7	13.8	3.8	10.9	2.5	7.9	5.3
#8	13.5	3.6	9.7	2.0	7.0	3.3
#11	10.7	6.9	9.2	4.2	6.5	2.8

TABLE 4.17 Corrected HELIOS coverage indices.

Treatment	Volume ($L/100m^3$)	Total B:M:T (ng/cm^2)	PI	HI
#6	1.0	22.6	41	79
#7	2.0	44.3	36	76
#8	4.0	39.2	30	60
#11	1.7	40.3	53	53

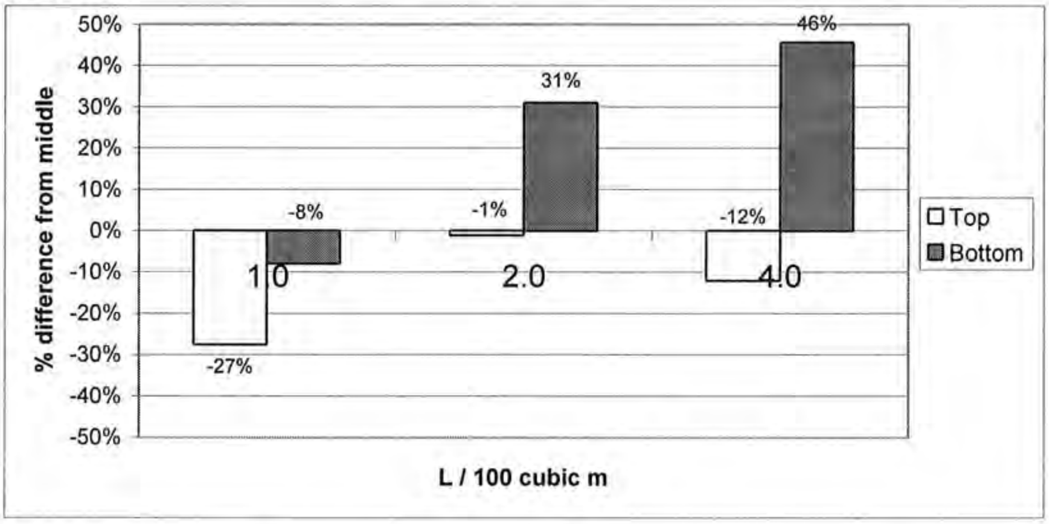
At medium speed there was little difference between the 2.0 and 4.0 L/100m^3 treatments (FIGURE 4.13). However the 1.0 L/100m^3 treatment was noticeably poorer, particularly at outer positions.

FIGURE 4.13 T3 Effect of volume on recovery at medium speed (3.4 kph).



The difference was particularly noticeable at the bottom of the tree, where recovery was actually 8% lower than the middle (FIGURE 4.14). This suggested that even at only 2-4 L/100m^3 runoff to the lower canopy might be occurring. The effectiveness of the tower fan is demonstrated by the small differences between the top and middle of only -1% and -12% in the 2.0 and 4.0 L/100m^3 treatments, respectively.

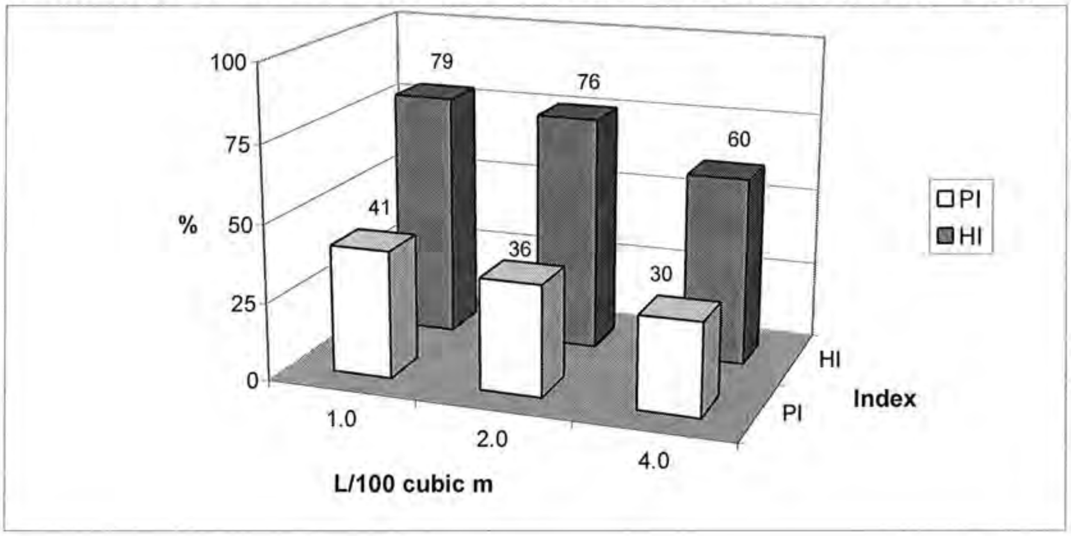
FIGURE 4.14 T3 Effect of volume on % Difference from Middle at medium speed (3.4 kph).



Compare this with SS SF45 hf (FIGURE 4.10) where the differences were –21% and –35%, respectively. It clearly shows that the straight through tower fan improved the evenness of coverage in the top half of the tree.

This explains the increase in HI at the lower volume, which rose because BO & BI were lower (FIGURE 4.15). This is not surprising given the increased delivery of droplets from the straight through tower fan into the TO and TI sites.

FIGURE 4.15 T3 Effect of volume on PI and HI at medium speed (3.4 kph).



The effects of nozzle type were minor, with the Albuz giving higher recovery but the TXVK giving more even overall coverage (FIGURE 4.16). The Albuz gave better coverage at the top of the tree, but poorer penetration at BI and MI. This gave a higher HI and lower PI than the TXVK (FIGURE 4.17).

FIGURE 4.16 T3 Effect of nozzle type on recovery at medium speed (3.4 kph) and volume (1.7-2.0 L/100m^3).

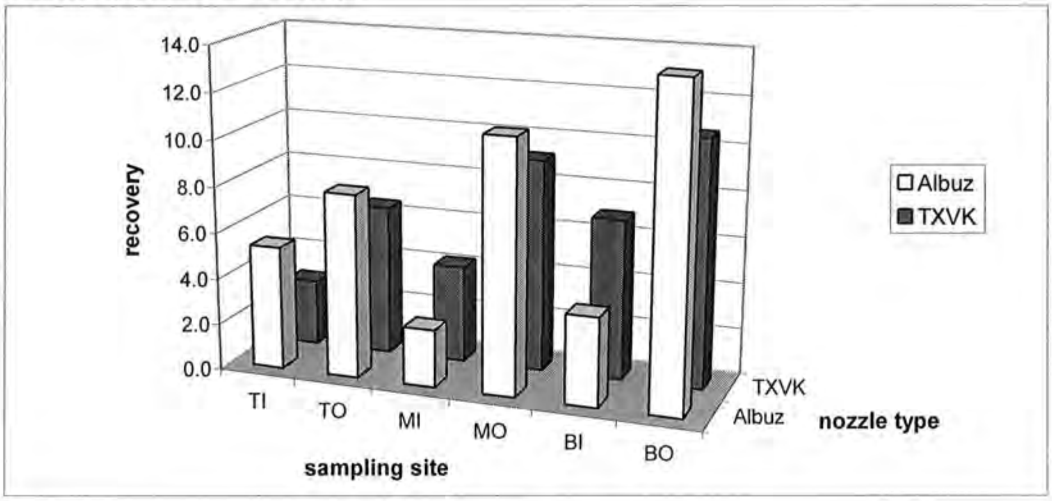
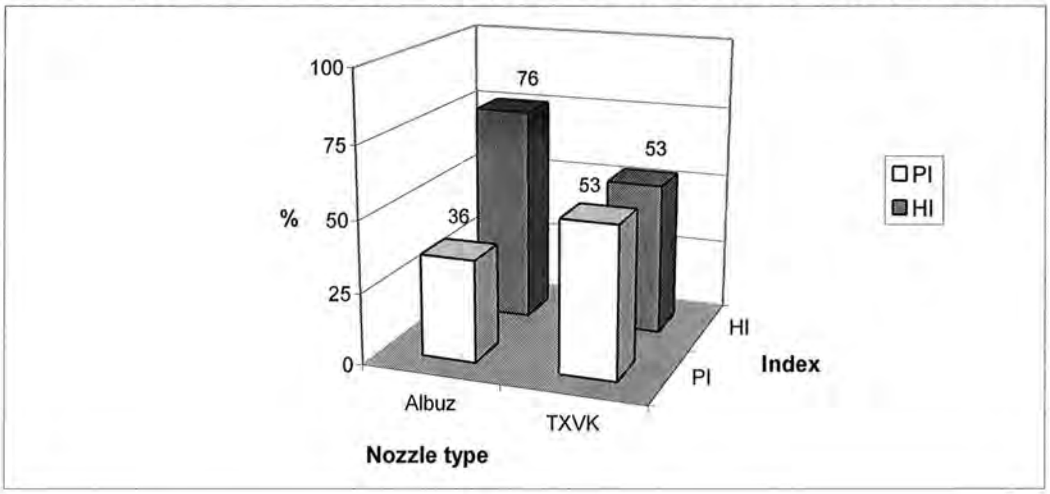
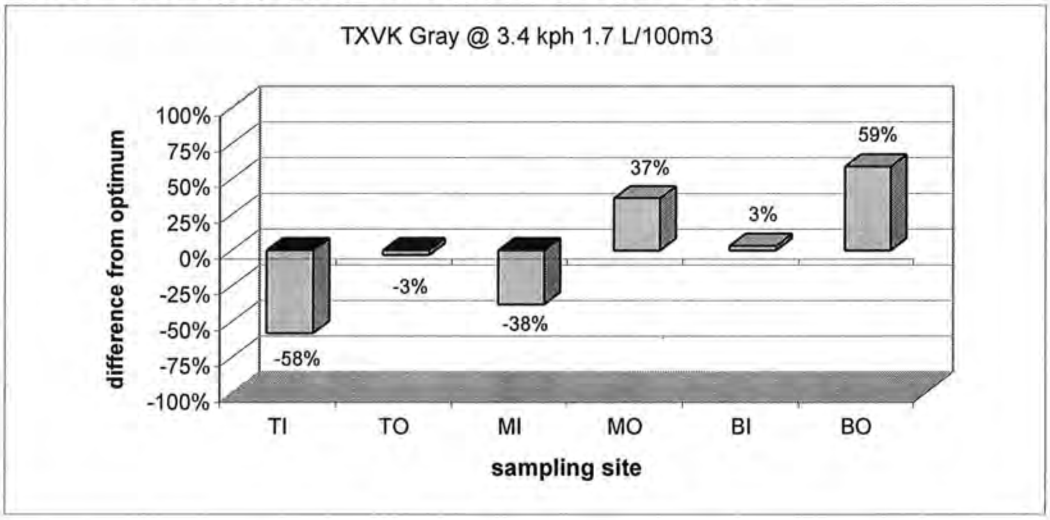


FIGURE 4.17 T3 Effect of nozzle type on PI and HI at medium speed and volume.



The distribution of coverage with the TXVK showed reasonably even coverage across the body of the tree but heavy overdosing at BO and underdosing at TI (FIGURE 4.18).

FIGURE 4.18 T3 Spray distribution across the canopy.



4.4 T4 Double-sided airshear mister with tower conveyor with 3 heads per side (DS CF T1).

The trial was carried out in one block of mature cultivar 344 at Arbuckle Orchards, Boreen Point. Characteristics of the Arbuckles 344 trial blocks are given in Section 2.2.1. The John Deere 6400 tractor was operated at 2000 rpm. For gears and speeds see Section 2.2.2. The trial plan matrix is given below (TABLE 4.18).

TABLE 4.18 T4 trial plan matrix.

	VERY LOW VOLUME	**LOW VOLUME**	**MEDIUM VOLUME**	**HIGH VOLUME**	
	x	**#1** 2.2 kph 1.0 L/100m^3 433 L/ha	x	x	**SLOW SPEED**
Treatment **Speed** **Volume/canopy** **Volume/ha**	**#5** 3.8 kph 0.5 L/100m^3 219 L/ha	**#2** 3.8 kph 1.0 L/100m^3 439 L/ha	**#4** 3.8 kph 2.0 L/100m^3 873 L/ha	**#6** 3.8 kph 3.7 L/100m^3 1625 L/ha	**MEDIUM SPEED**
	x	**#3** 5.2 kph 1.0 L/100m^3 437 L/ha	x	x	**FAST SPEED**

The sprayer, designated DS CF T1, was a 2000L towed airshear sprayer with double-side tower (see FIGURE 4.19). Sprayer setup is given in TABLE 4.19. The machine was brand new and not set up specifically for macadamias.

TABLE 4.19 T4 Sprayer setup.

Sprayer and tank size	Airshear DS CF T1, 2000 L
Fan size, pitch and gear	320 mm diameter centrifugal fan
Average measured air inlet speed	27.1 m/sec
Estimated fan output *	15,800 m^3/hr total output, 7,900 m^3/hr per side
Conveyor	Double-sided tower with 3 heads at 0.6, 1.6 and 2.8 m above ground

* Estimated fan output was based on an entrainment factor of 2.0 as per Battaglia *et al.* (1997).

FIGURE 4.19 T4 The DS CF T1 sprayer in action.

TABLE 4.20 T4 Treatments, spray volumes, restrictors and pressures

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
	x	#1 1.0 L/100m^3 Red No.6 2.0 bar 6.5 L/min	x	x	**SLOW SPEED**
Treatment **Volume/canopy** **Restrictors** **Pressure** **Flow/side**	**#5** 0.5 L/100m^3 Red No.5 2.0 bar 5.6 L/min	**#2** 1.0 L/100m^3 Red No.7 2.5 bar 11.2 L/min	**#4** 2.0 L/100m^3 Red No.11 2.0 bar 22.3 L/min	**#6** 3.7 L/100m^3 Red No.15 2.4 bar 41.5 L/min	**MEDIUM SPEED**
	x	**#3** 1.0 L/100m^3 Red No.9 2.0 bar 15.2 L/min	x	x	**FAST SPEED**

Weather conditions were good although there were changes in wind direction during spraying (see TABLE 4.21). Temperatures were low with moderate humidity and the ΔT for all treatments was over a narrow range of 4.0 – 5.5.

TABLE 4.21 T4 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (°C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	1.0	S	20.0	68	4.0
#2	0.8	S/E	23.3	60	5.5
#3	0.6	S/E	23.9	58	5.5
#4	0.6	N/E	22.9	61	5.0
#5	1.0	S	23.1	60	5.5
#6	0.6	S	20.0	65	4.5

The dose of Helios applied in each treatment is given in TABLE 4.22.

TABLE 4.22 T4 HELIOS dosage applied.

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#1	1.0	8.0	34.6	0.792
#2	1.0	8.0	35.1	0.803
#3	1.0	8.0	35.0	0.799
#4	2.0	4.0	34.9	0.798
#5	0.5	16.0	35.0	0.801
#6	3.7	2.0	32.5	0.743

The corrected average Helios recovery for each treatment are given in TABLE 4.23 and the PI and HI in TABLE 4.24.

TABLE 4.23 T4 Corrected HELIOS recovery (ng/cm^2 leaf) based on an applied dose of 0.6 $ml/100m^3$

Treatment	BO	BI	MO	MI	TO	TI
#1	10.1	2.4	7.6	3.3	3.4	1.4
#2	8.2	1.9	7.2	5.3	0.8	0.4
#3	8.6	1.7	8.9	3.4	2.0	1.3
#4	16.8	3.8	12.5	3.4	9.0	4.9
#5	9.7	2.7	7.4	2.6	2.6	1.4
#6	5.9	1.6	6.8	3.1	0.7	0.3

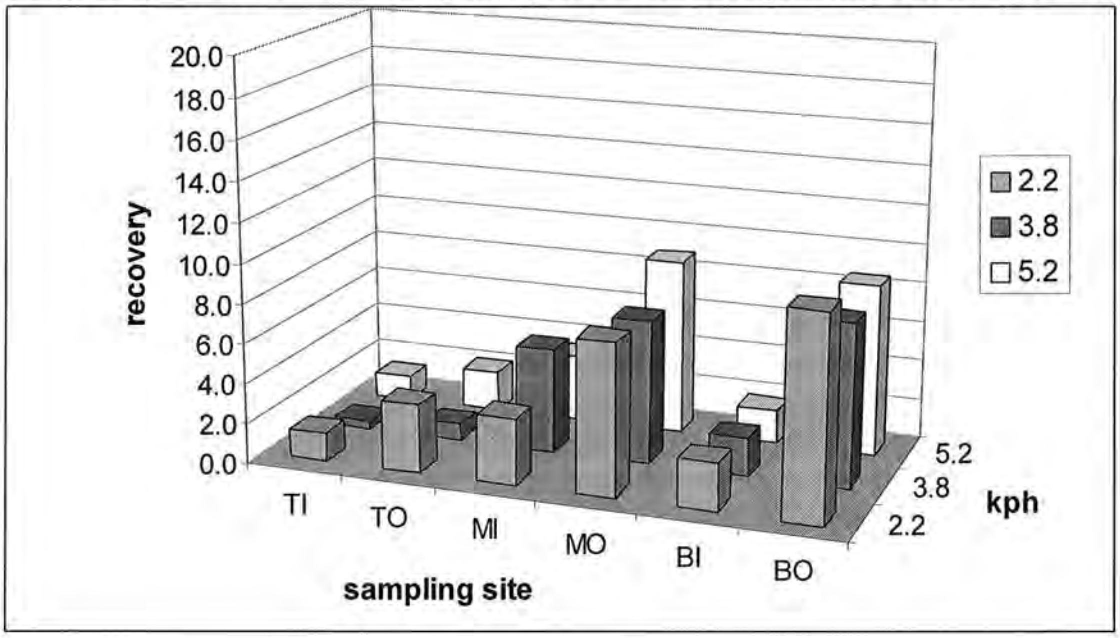
TABLE 4.24 T4 Corrected HELIOS total and coverage indices.

Treatment	Volume (L/100m^3)	Total Helios (ng/cm^2)	PI %	HI %
#1	1.0	28.4	34	39
#2	1.0	23.9	47	13
#3	1.0	25.9	33	32
#4	2.0	50.4	32	67
#5	0.5	26.3	34	32
#6	3.7	18.4	37	13

Treatments #2 and #6 had particularly poor recovery in the top of the tree (HI=13%), but higher PI than other treatments. Treatment #4 had the highest overall recovery, a high HI of 67%, and similar penetration to other treatments.

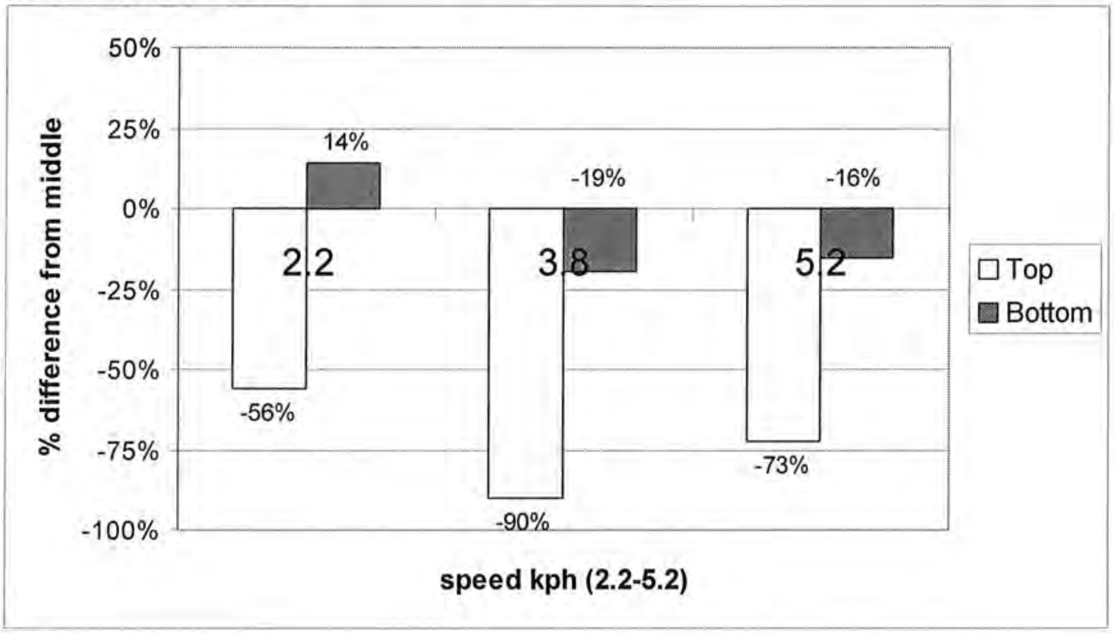
Changing speed at low volume had little obvious effect on recovery (FIGURE 4.20). Coverage at all 3 speeds was higher at BO than BI, and at MI than BI. Recovery at TO and TI was poor in all cases. The small effect of speed on recovery was attributed to the low air volume per unit canopy at all speeds. This sprayer did not appear to deposit droplets by canopy air displacement, but rather by drift. At 1.0 L/100m^3 no runoff occurred.

FIGURE 4.20 T4 Effect of change in speed on recovery at low volume (1.0 L/100m^3).



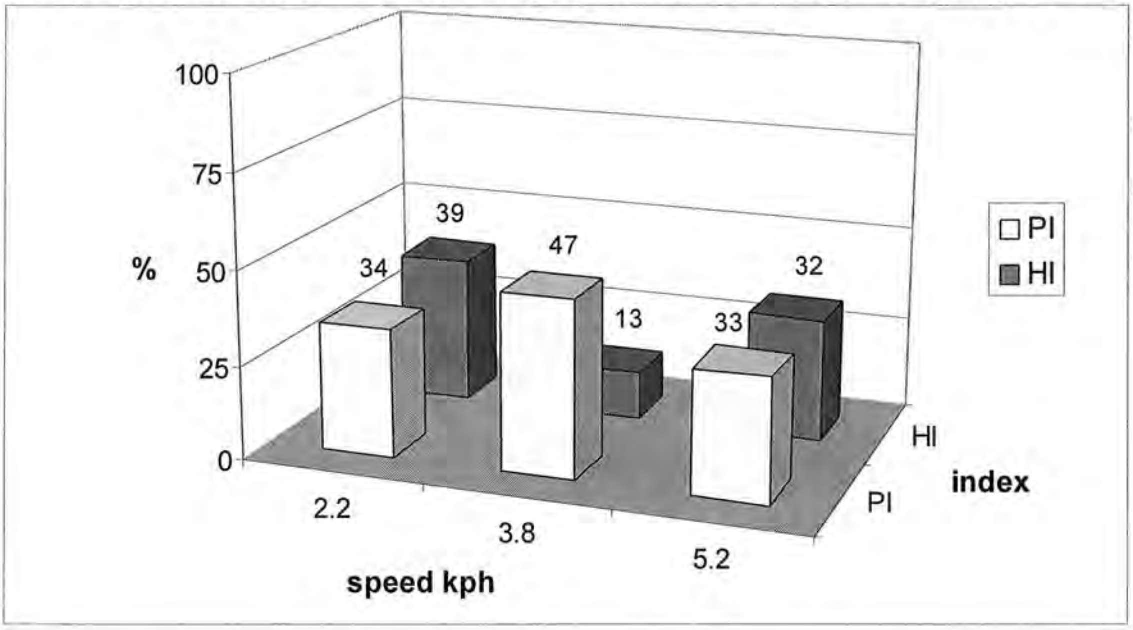
However comparison with coverage in the middle of the tree showed that at 2.2 kph coverage at the bottom was higher than in the middle (FIGURE 4.21). Coverage at the top was also better but still 56% lower than the middle. At higher speeds the top was 70-90% lower than the middle.

FIGURE 4.21 T4 Effect of change in speed on % Difference from Middle at low volume (1.0 L/100m³).



The figures for PI and HI (FIGURE 4.22) were not consistent but highlighted the generally poor penetration (PI = 33-47%) and coverage at the top of the canopy (HI = 13-39%) at all speeds.

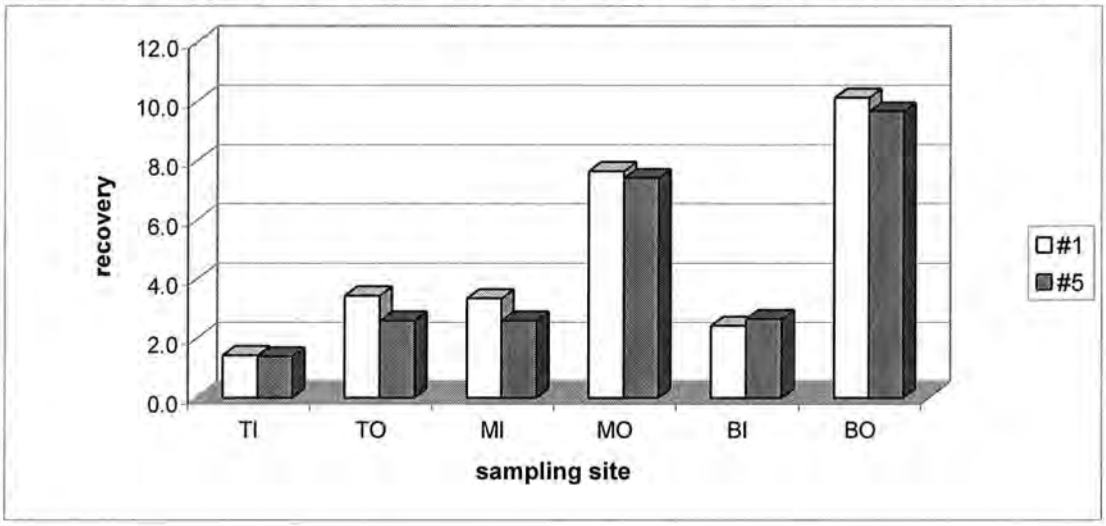
FIGURE 4.22 T4 Effect of change in speed on PI and HI at low volume (1.0 L/100m³).



Anecdotal evidence from growers using airshear sprayers suggests that the application volume of about 2 L/100m³ gives the best results (Gillett, pers. comm.). This equated to a total flow rate of approximately 22 L/minute per side, equivalent to 440 L/hr for each head. In fact this was the best treatment #4 in our trial.

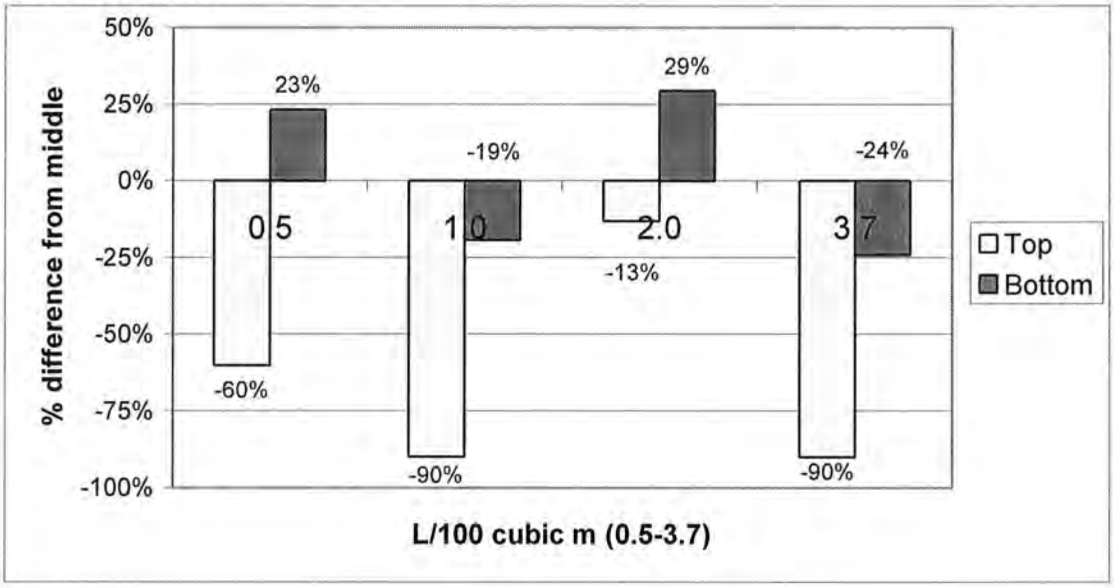
Since droplets size is directly proportional to flow rate, changing the flow rate meant that treatments were not directly comparable, ie. we had changed more than one variable. For example based on equivalent flow rates one could have expected treatments #1 & #5, and #2 & #3 to be the most similar, despite one being twice the volume of the other. This is in fact borne out be a comparison of the recovery patterns (FIGURE 4.23).

FIGURE 4.23 T4 Comparison of treatments #1 (6.5 L/min, 1.0 L/100m³) and #5 (5.6 L/min, 0.5 L/100m³) with similar flow rates but different volumes/unit canopy.



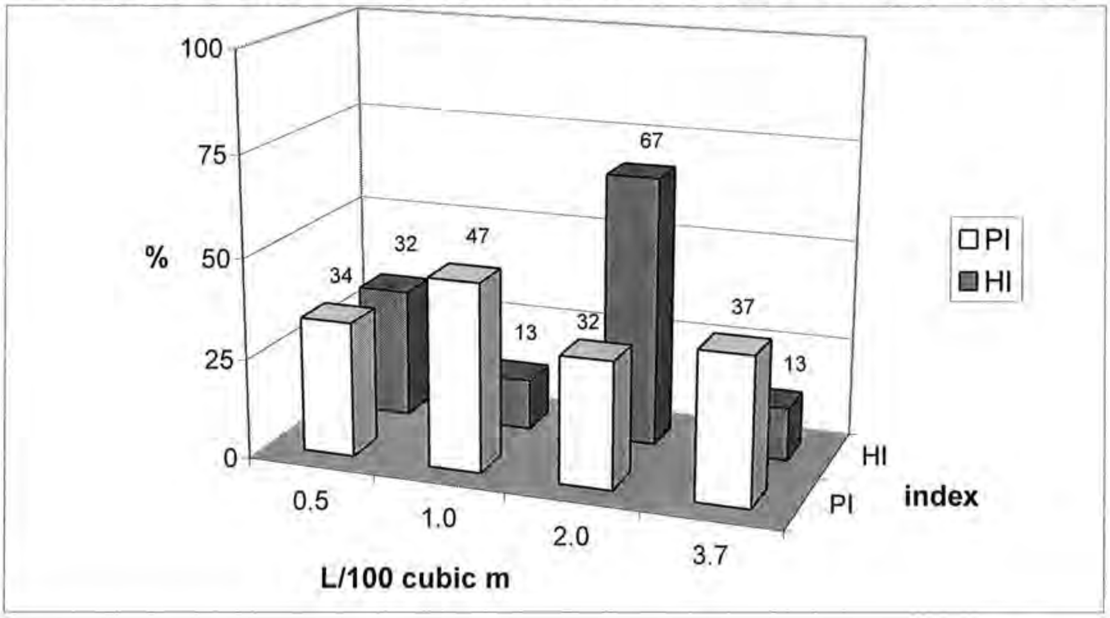
Treatment #4 (2.0 L/100m³) with 22 L/min output per side, that is 7.3 L/min per head, gave the highest recovery and also the most uniform recovery when comparing the top and bottom with the middle (FIGURE 4.24).

FIGURE 4.24 T4 Effect of change in volume on % Difference from Middle at medium speed (3.8 kph).



The results highlighted the reliance of airshear spraying on drift to achieve penetration of the canopy. The airstream itself could not displace the air in the canopy which, based on the formula of Cunningham *et al.* (c.1996, p.21), would require a speed of only 0.2 kph. In treatment #6 the flow rate was so high that proper droplet formation could not occur. The high speed airstream did create droplets but these were very large and rapidly fell under gravity on the outside of the canopy or on the ground, rather than drifting. Such flow rates may give acceptable results in tree crops with shorter narrower canopies such as palmette stonefruit but are totally unsuited to large tall canopies.

FIGURE 4.25 T4 Effect of change in volume on PI and HI at medium speed (3.8 kph).



The trial clearly showed that airshear sprayers achieve their coverage primarily through drift.

Given that airshear sprayers are dedicated low volume sprayers and that flow rate determines droplet size, it would seem that airshear sprayers have an optimum flow rate rather than an optimum application volume. The optimum flow rate would appear to be in the range 300-400 L/hr or 5.0 - 6.7 L/min per head. This could possibly still equate to high application volumes in very small canopies.

Because for airshear sprayers the primary mode of deposition of droplets is by drift, speed is not a critical factor in their operation. Hence the longterm support for airshear spraying by some larger growers who need to spray large areas in a short time. There is no doubt that they can be effective for most pests but the inability to apply high volumes in large canopies may compromise control of husk spot.

Because airshear sprayers are dedicated low volume sprayers suitable for Concentrate spraying it is critical to correctly calculate the appropriate Concentration based on the appropriate volume for Dilute spraying. For example at 2.0 L/100m^3, which gave the best results in the above trial, the mixing Concentration would be 3X (6/2) or 3 times the Dilute concentration.

4.5 T5 & T13 Double-sided Controlled Droplet Application sprayer with 4 fans per side (DS 8TF).

4.5.1 T5 setup

The trial was carried out one block of mature cultivar 344 at Arbuckle Orchards, Boreen Point. Characteristics of the Arbuckles 344 trial block are given in Section 2.2.1. The John Deere 6400 tractor was operated at 1500 or 1800 rpm. For gears and speeds see Section 2.2.2.

The initial treatments (#7 - #11) carried out in May 2001 were confusing and therefore two follow-up treatments (#12 & #13) were applied and assessed in June 2002 (TABLE 4.25). The treatments and results are presented together.

TABLE 4.25 T5 & T13 trial plan matrix.

	VERY LOW VOLUME	**LOW VOLUME**	**MEDIUM VOLUME**	
Treatment **Speed** **Volume/canopy** **Volume/ha**	**#11** 2.0kph @ 1800rpm 0.5 L/100m^3 225 L/ha **#12** 2.1kph @1800rpm 0.5 L/100m^3 220 L/ha	**#7** 2.3kph @ 1500rpm 1.0 L/100m^3 439 L/ha **#10** 2.0kph @ 1800rpm 1.0 L/100m^3 450 L/ha **#13** 2.1kph @ 1800rpm 1.0 L/100m^3 440 L/ha		**SLOW SPEED**
		#9 3.8kph @1500rpm 1.0 L/100m^3 448 L/ha	**#8** 3.8kph @ 1500rpm 2.0 L/100m^3 864 L/ha	**MEDIUM SPEED**

The sprayer specifications are outlined in TABLE 4.26, and the sprayer is illustrated in FIGURE 4.26. The jets, pressures and cowling modifications are given in TABLE 4.27.

FIGURE 4.26 T5 The DS 8FT sprayer in action.

TABLE 4.26 T5 & T13 Sprayer setup.

Sprayer and tank size	Span CDA DS 8FT with 2000 L tank
Fan size, pitch and gear	8 x 620 mm fans with 470 mm effective diameter. Spinning discs and Albuz jets were placed centrally in front of the fan.
Average measured air inlet speed * @ tractor rpm	T5 @ 1500 rpm = 14.6 m/sec T5 @ 1800 rpm = 17.3 m/sec T13 +C @ 1800 rpm = 11.1 m/sec
Estimated fan output + @ tractor rpm	T5 @ 1500 rpm = 29,985 m^3/hr per head = Total of 119,941 m^3/hr per side T5 @ 1800 rpm = 35,543 m^3/hr per head = Total of 142,173 m^3/hr per side T13 +C @ 1800 rpm = m^3/hr per head = Total of 91,397 m^3/hr per side
Conveyor	Double-sided tower with 4 individual hydraulically driven fan heads at 1.0, 2.3, 3.8 and 5.5 m above ground on each side.
Fan cowlings	#12 +C with cowling modification to each fan #6 - #11, #13 –C cowl with original Span fan cowlings

* There was relatively high variability between individual fans, eg. at 1500 rpm average inlet speed varied between 12.7 (Right) and 16.4 (Left) m/sec.
+ For comparative purposes an entrainment factor of 2 has been assumed, but the poor trial results suggest it may have been much lower with the original narrow fan cowlings.

TABLE 4.27 T5 & T13 Jets and pressures

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	
Treatment **Volume/canopy** **Jets per side** **Pressure**	**#11** 0.5 L/100m^3 4 x D1.5 disc* @ 6 bar **#12** 0.5 L/100m^3 4 x Albuz ATR Yellow @ 5.5 bar **+ MODIFIED COWLING**	**#7** 1.0 L/100m^3 4 x D4 disc @ 2 bar **#10** 1.0 L/100m^3 4 x D3 disc @ 6 bar **#13** 1.0 L/100m^3 8 x Albuz ATR Yellow @ 5.5 bar		**SLOW SPEED**
		#9 1.0 L/100m^3 4 x D4 disc @ 6 bar	**#8** 4.0 L/100m^3 2 x D6 plus 2 x D7 disc @ 5 bar	**MEDIUM SPEED**

* All restrictors were Spraying Systems solid stream stainless steel discs, sizes D1.5 to D7. The flow rates for these jets are given in Section 2.2.3.

The weather conditions (TABLE 4.28) for the first 3 treatments of the trial were good with low temperatures, little wind and a ΔT below 5. The treatments in 2002 had very low humidity, higher wind speeds and a ΔT between 7.5 and 9.5. With winds from the S and SE the N-S rows were somewhat exposed but as it was the eastern sides that were sampled any effects of wind were likely to increase, rather than decrease, recovery.

TABLE 4.28 T5 & T13 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (^{0}C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#7	0.5	S/E	23.5	68	4.0
#8	0.4	S	19.8	82	2.5
#9	0.3	E	21.0	78	3.0
#10	0.9	S	22.5	55	6.0
#11	0.6	S/E	24.5	48	7.0
#12	1.4	S/SE	23.0	33	9.5
#13	2.5	SE	20.0	40	7.5

4.5.2 T13 Modifications to the DS 8FT sprayer.

The aim of the T13 trial was to determine the causes of the poor results in T5 with the CDA spinning disk sprayer. The possible causes of the poor results in T5 were (1) loss of droplets from the airstream, (2) inappropriate droplet size and (3) low entrainment due to low air ducting. Unfortunately the grower had already replaced the spinning disks with hollow cone jets running at relatively low pressure. It was therefore decided to apply two treatments with hollow cones which replicated treatments in T5, but with a modified cowling in one instance. The modified cowling consisted of 200 mm wide plastic garden edging attached to the front of the fan shroud and slightly in front of the fan blades. This increased the depth of the cowling from approximately 50 to 250 mm wide.

When tested for the 2nd trial it was found that the average air inlet speed at 1800 rpm was well below (11.1 m/sec) that found in T5 (17.3 m/sec). This machine was known to be at the limits for the hydraulic fan motors as evidenced by overheating problems with the hydraulic pump reported by the grower. The lower inlet speed was therefore attributed to a reduction in hydraulic pressure. This reduction was not significant to the trial since droplet size was not dependent upon fan speed. Although the droplet size in T5 was not known, the droplet size in T13 for the Albuz ATR Yellow nozzles at 5.5 bar was approximately 108 μm VMD, comparable with Red and Green nozzles at 15 bar.

The results of treatment #12 with the cowling were astonishing. Despite there being no visible difference in the spray pattern with and without the cowling, there were large differences in recovery. In fact the results with the cowling were the best achieved in any of our tests for evenness of deposit. PI was 72%, meaning that the recovery in the inner canopy was 72% of that achieved on the outside. HI was 97%, meaning that recovery at the top of the canopy was 97% of that at the bottom. Given that the fan heads were placed at 1.00, 2.30, 3.75 and 5.35 metres above ground this is not completely surprising. It suggests that delivery of the correct droplet size, with sufficient air behind it at the optimum height can produce excellent recovery. The results mirrored the success of the single through fan in T3.

The results of treatment #13 without the cowling were comparable to those achieved in T5, despite the use of hollow cone jets. This strongly suggested that loss of droplets from the airstream was affected by cowling design rather than by droplet formation. An alternative explanation is that the air produced by each head could not "carry" the increased spray volume. This seems unlikely with each head producing approximately 22,849 m^3/hr, assuming an entrainment factor of 2. Of course it could be that the entrainment factor of the fans without cowlings is much less than 2, perhaps only 1, due to air spillage. Still a flow of only 1.55 L/min into 12,000 m^3/hr of air should not be unreasonable.

We believe the results show the importance of air ducting in carrying droplets to, and into, the canopy irrespective of spray volume. The delivery of high volumes of air from 5.35 metres above the ground can penetrate the canopy interior better than air directed from a low profile sprayer.

4.5.3 T5 & T13 Results and discussion

The average Helios doses and recovery results are given in TABLES 4.29 and 4.30, respectively.

TABLE 4.29 T5 & T13 HELIOS dosage applied

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#7	1.0	8.0	35.1	0.803
#8	2.0	4.0	34.6	0.790
#9	1.0	8.0	35.8	0.819
#10	1.0	8.0	36.0	0.823
#11	0.5	16.0	36.0	0.823
#12	0.5	16.0	35.2	0.805
#13	1.0	8.2	36.1	0.825

TABLE 4.30 T5 & T13 Corrected HELIOS recovery based on an applied dose of 0.6 $ml/100m^3$.

Treatment	BO	BI	MO	MI	TO	TI
#7	15.4	2.3	10.4	2.9	4.2	2.0
#8	7.8	2.2	5.6	1.6	1.6	1.8
#9	7.9	1.1	7.3	1.6	2.5	0.7
#10	11.8	2.3	8.5	2.6	4.1	1.7
#11	7.5	1.6	6.9	2.1	3.0	1.6
#12	9.2	5.2	7.6	6.2	7.7	6.3
#13	20.3	3.6	11.8	2.9	4.2	1.8

The treatments in 2002 with the hollow cone jets gave the highest recovery but the pattern of penetration without the cowling modification (-C) was very similar to the results with spinning disks (TABLE 4.31).

TABLE 4.31 T5 & T13 Corrected HELIOS coverage indices.

Treatment	Volume ($L/100m^3$)	Total B:M:T (ng/cm^2)	PI	HI
#7	1.0	37.3	24	35
#8	2.0	20.6	38	34
#9	1.0	21.0	19	35
#10	1.0	31.1	27	41
#11	0.5	22.7	31	51
#12 (+C)	0.5	42.2	72	97
#13 (-C)	1.0	44.7	23	26

Volume had very little effect on recovery at low speed (FIGURE 4.27) or medium speed (FIGURE 4.28).

FIGURE 4.27 T5 Spinning disc jets: Effect of change in volume on recovery at low speed (2.0 kph).

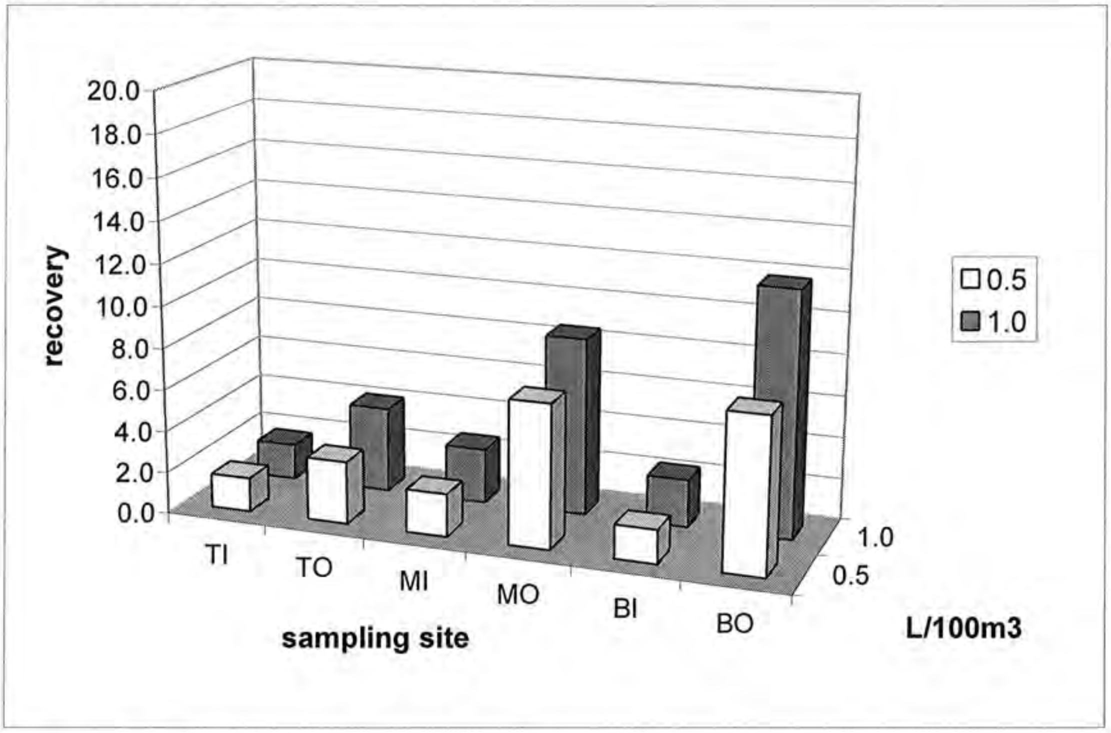
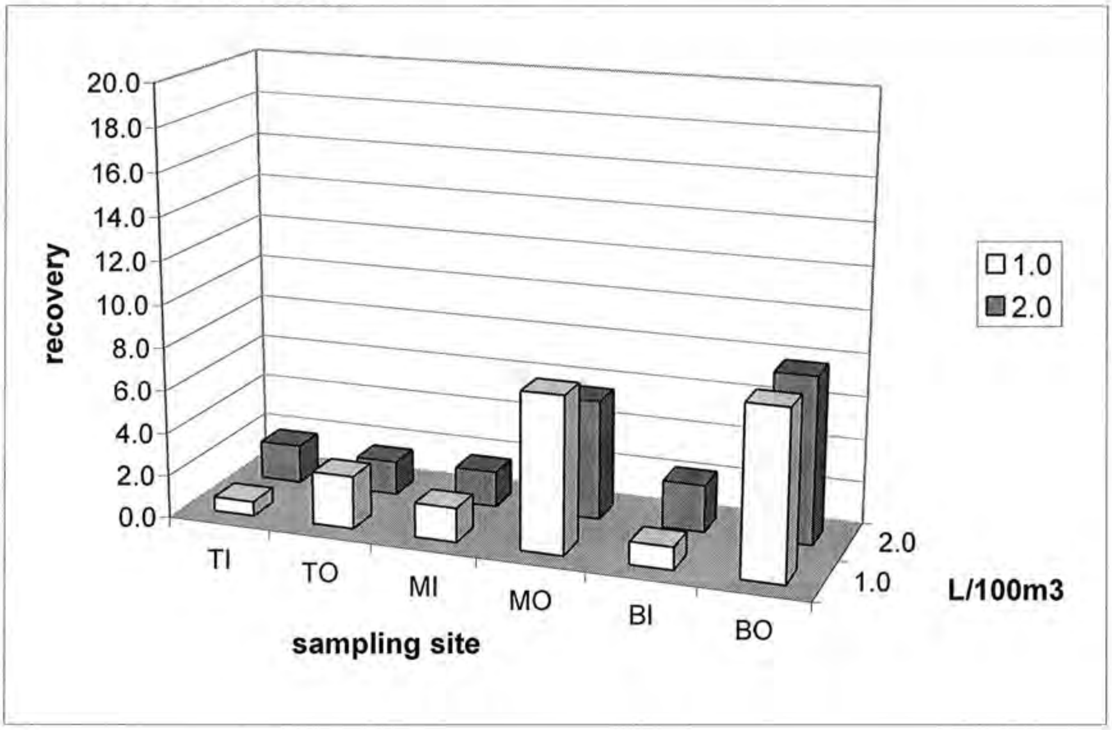
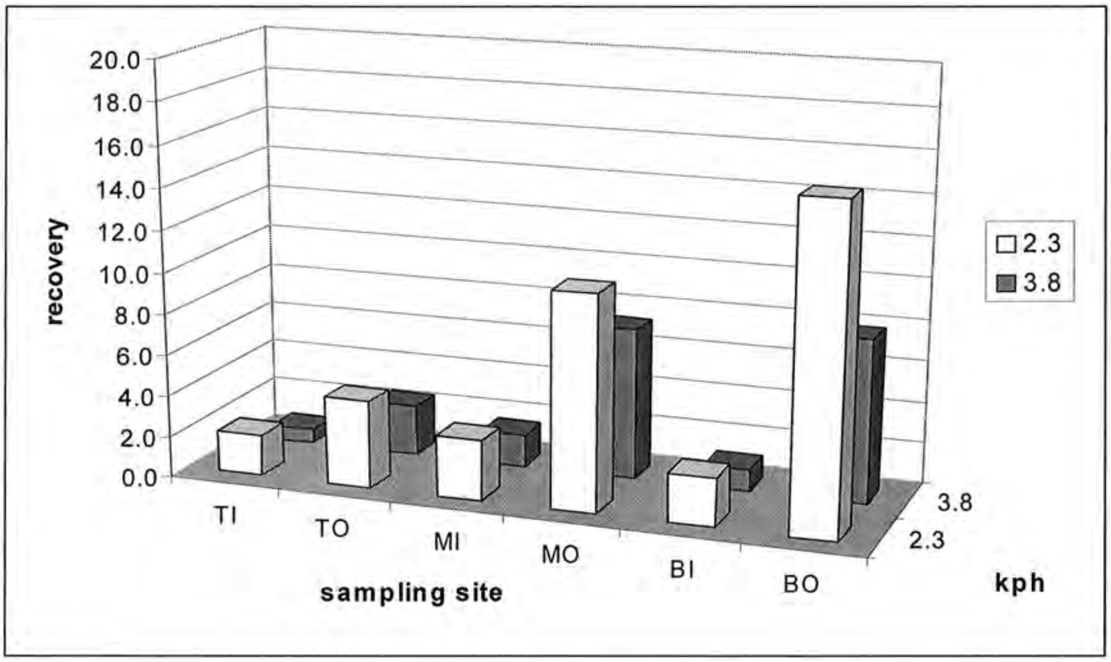


FIGURE 4.28 T5 Spinning disc jets: Effect of change in volume on recovery at medium speed (3.8 kph).



Reducing speed did improve recovery at low volume (FIGURE 4.29), particularly at BO and MO.

FIGURE 4.29 T5 Spinning disc jets: Effect of change in speed on recovery at low volume (1.0 L/100m^3).



Hollow cones did improve recovery at BO and MO (FIGURE 4.30) but had little effect on canopy penetration (FIGURE 4.31).

FIGURE 4.30 T5 & T13 Spinning disc (SD) vs Hollow cone (HC): Effect of jet type on recovery at low speed (2.0-2.1 kph) and low volume (1.0 L/100m^3).

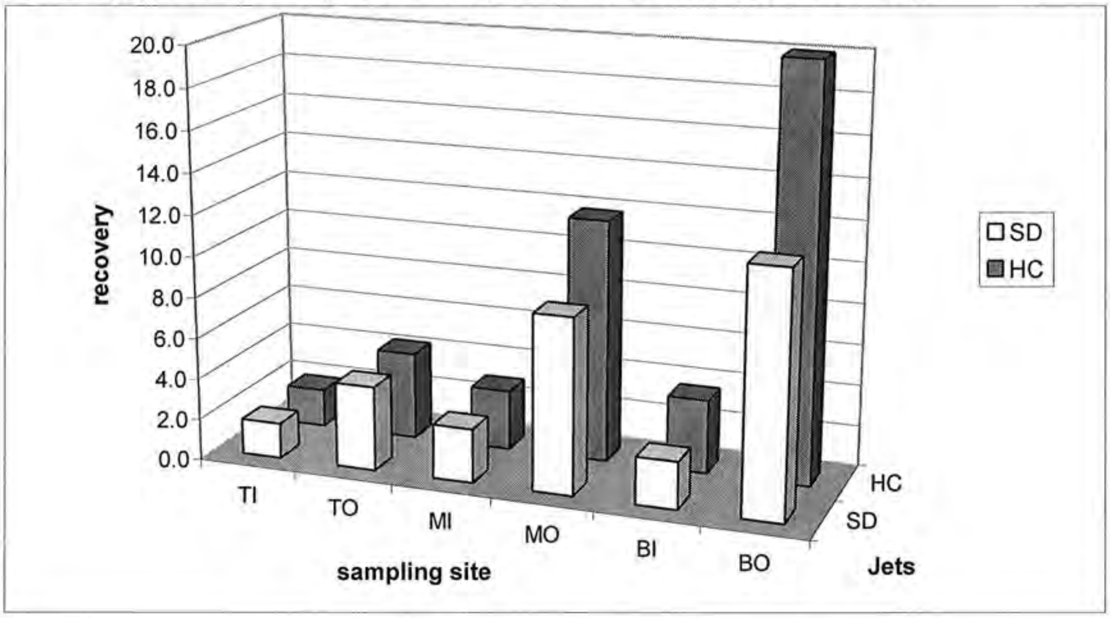
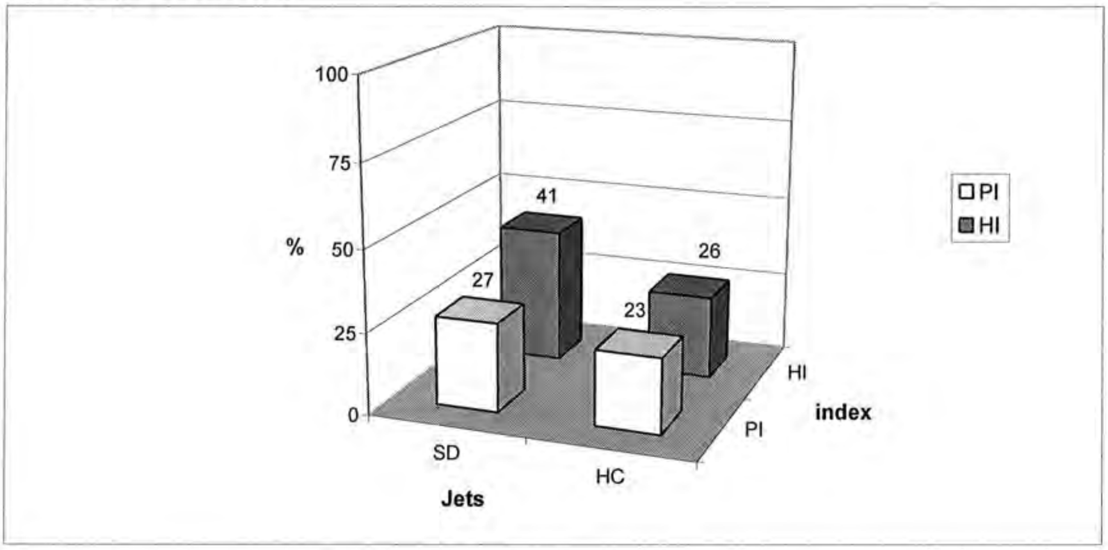


FIGURE 4.31 T5 Effect of nozzle type on PI and HI at low speed (2.0-2.1 kph) and low volume (1.0 L/100m³).



The simple modification to the fan cowling had an amazing effect on recovery at the top of the tree (FIGURE 4.32) and on canopy penetration (FIGURE 4.33).

FIGURE 4.32 T5 & T13 Spinning disc (SD) vs Hollow cone (HC): Effect of jet type and cowling modification on recovery at low speed (2.0-2.1 kph) and very low volume (0.5 L/100m³).

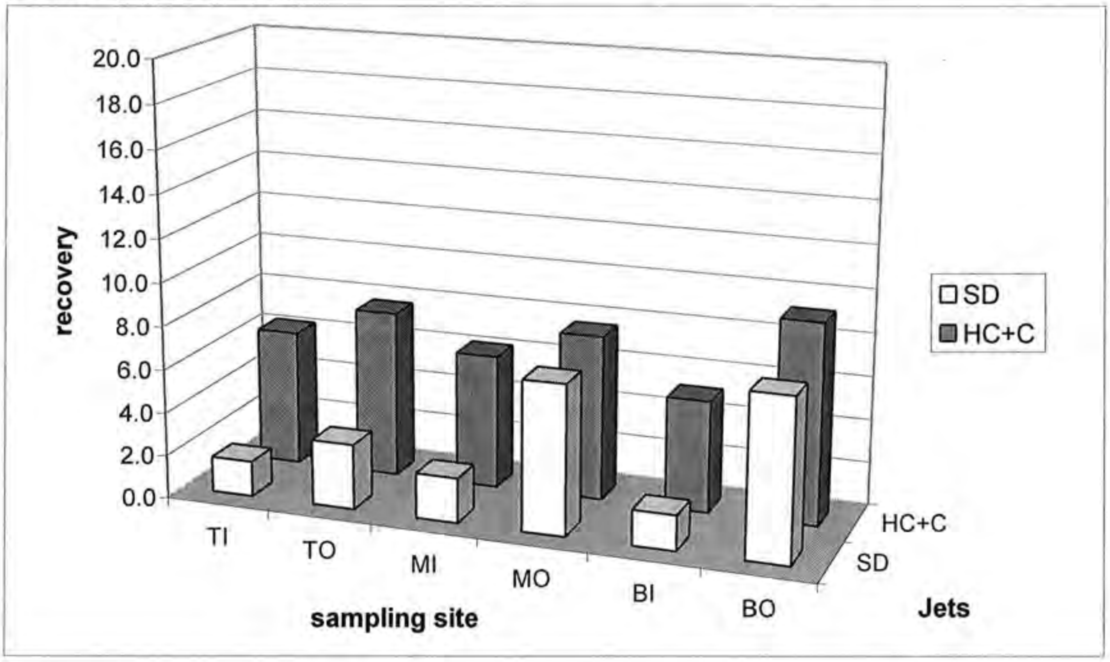
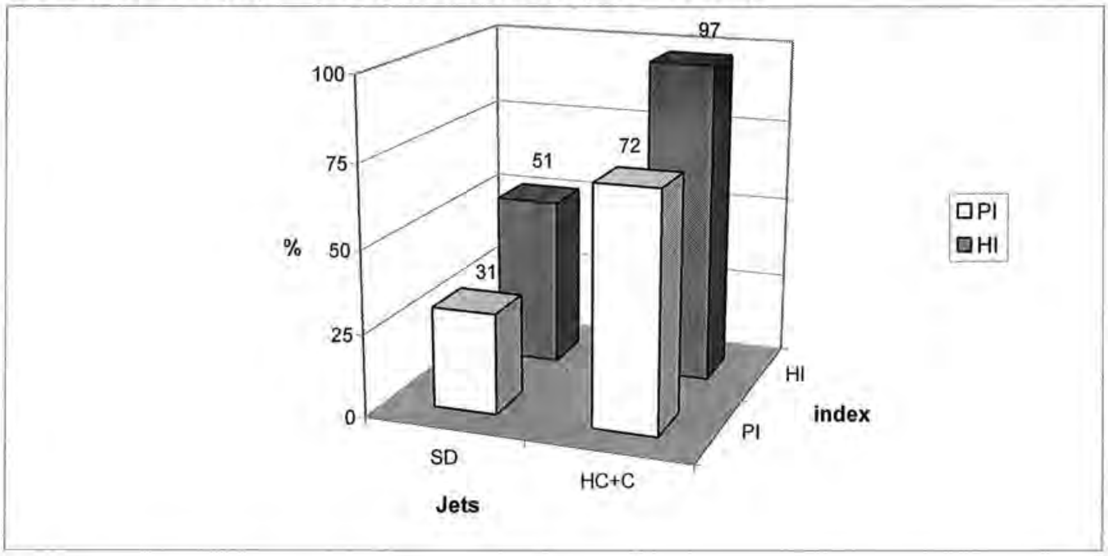


FIGURE 4.33 T5 Effect of nozzle type and cowling modification on PI and HI at low speed (2.0-2.1 kph) and very low volume (0.5 L/100m^3).



4.5.4 T5 & T13 Implications

The very poor performance of the original spinning disc sprayer, despite the highest air volume of any machine, was a big surprise. However it was immediately apparent when the sprayer went over a bump that sheets of spray fell behind the sprayer, indicating that droplets were being lost from the airstream.

At first this was attributed to the fact that droplets generated by spinning discs are thrown at right angles to the airstream and have to change direction. Increasing fan and spinning disc speed would increase airflow but would also increase angular momentum and reduce droplet size. Thus fan speed could not be adjusted to reduce this effect. An alternative explanation could be that the fans were too efficient and were in fact blowing the droplets right through the canopy. This unlikely scenario is illustrated in APPENDIX C. However the sheets of spray behind the sprayer (see FIGURE 4.26) did not support idea.

Conversion of the sprayer from spinning disks to hollow cones, or perhaps even solid cones, offers several advantages. These include:

- The flexibility to use different jets and known droplet sizes.
- The option of applying very high volumes for improved husk spot or scale control.
- The option to run the fans at lower speeds without affecting droplet size.
- A reduction in loss of droplets over uneven ground.

However the failure of the Albuz Yellow hollow cones to improve recovery and penetration suggested that spillage of air was more critical. The air volumes had been calculated on the basis of an entrainment factor of 2, as recommended by Cunningham *et al.* (c.1996a, p.19) for dense orchard canopies. However the very narrow shroud and its placement in line with the fan, probably mostly for fan protection, was a possible cause of air spillage. The attachment of 200 mm of plastic garden edging to the front of the fan did not make an obvious visual difference to the spray compared with hollow cone alone, but the two combined did eliminate the loss of sheets of droplets.

4.6 Double-side low-profile sprayer with double fans (DS DF45)

This trial did not go well. Two treatments, #2 and #3, were not applied as planned due to rushing to avoid showers during very changeable weather. The treatments still allowed useful comparisons but did not meet the planned treatment matrix (TABLE 4.32).

TABLE 4.32 T6 Treatment numbers and details

	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
	x	#4 2.0 kph 2.0 L/100m^3 1079 L/ha	x	SLOW SPEED
Treatment Speed Volume/canopy Volume/ha	#1 3.4 kph 1.0 L/100m^3 524 L/ha	#2 * 3.4 kph 2.4 L/100m^3 1271 L/ha	x	MEDIUM SPEED
	x	#5 5.0 kph 2.0 L/100m^3 1040 L/ha	#3 + 5.0 kph 2.7 L/100m^3 1461 L/ha	FAST SPEED

* Treatment #2 spray volume was higher than planned (2.0 → 2.4 L/100m^3) due to an error in increasing pressure from 15 to 23 bar.
+ Treatment #3 speed was higher than planned (3.4 → 5.0 kph) due to an error in use of a higher gear (4th Low).

TABLE 4.33 T6 Jets and pressures

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	
	x	#4 2.0 L/100m^3 1 Rd, 8 Or 15 bar	x	SLOW SPEED
Treatment Volume/canopy Jets per side Pressure	#1 1.0 L/100m^3 8 Or 15 bar	#2 2.4 L/100m^3 5 Or, 5 Rd, 2 Gr 23 bar	x	MEDIUM SPEED
	x	#5 2.0 L/100m^3 6 Rd, 8 Gr 15 bar	#3 2.7 L/100m^3 10 Bl, 4 Gr 15 bar	FAST SPEED

FIGURE 4.34 T6 the DS DF45 sprayer in action.

Weather conditions were difficult for this trial (TABLE 4.34). Treatment #1 had to be repeated the following day after rain fell after only 3 trees had been sampled. Treatment #4 was completely rained off and had to be repeated next day. Winds were generally light and all treatments had a ΔT below 5.

TABLE 3.34 T6 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (°C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	0.3	E	19.9	97	0.5
#2	0.5	E	24.6	74	3.5
#3	0.4	E	23.8	69	4.0
#4	Nil	Nil	21.6	88	1.5
#5	Nil	Nil	17.8	96	<0.5

The dose of Helios applied is given in TABLE 4.35. In treatment #2 the tank agitator was not working effectively and in treatment #3 the flow rate and spray volume were so high that the conveyor was flooded, with spray running off the sides. This was caused by the placement of the jets inside the conveyor and the inability of the air to capture the droplets before they hit the sides. Nozzle extensions of 100-150 mm would have been sufficient to avoid this.

TABLE 4.35 T6 HELIOS dosage applied

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#1	1.0	6.0	31.4	0.590
#2	2.4	3.0	38.1	0.715
#3	2.7	1.5	21.9	0.411
#4	2.0	3.0	32.4	0.607
#5	2.0	3.0	31.2	0.585

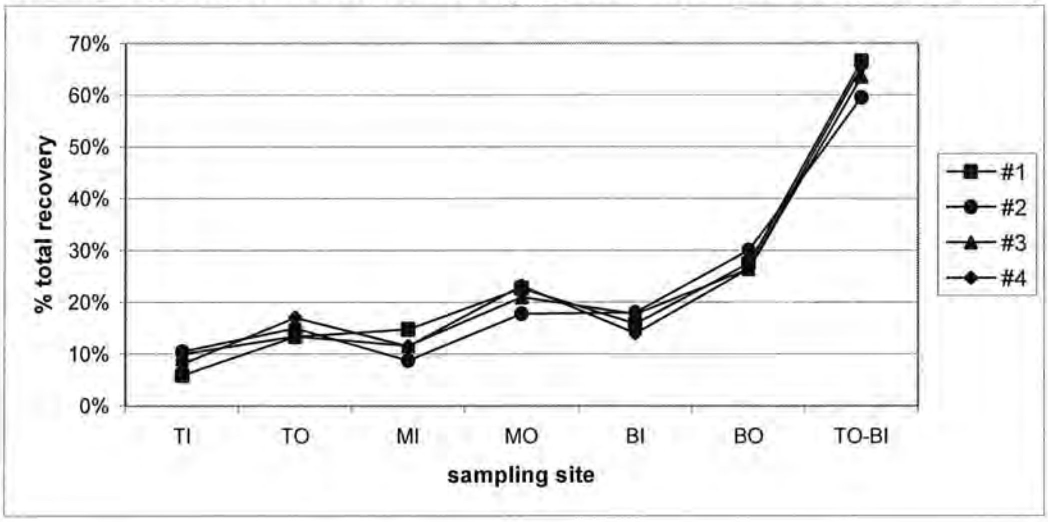
The results for treatments #1 to #4 are given in TABLE 4.36. Unfortunately the leaf sample areas for #5 were corrupted in the lab and therefore no meaningful data could be collected. Recovery for treatment #3 was higher than the other treatments but the reasons for this are not clear. However treatment #3 was at the higher volume of 2.7 L/100m3 with the larger jets and droplet sizes.

TABLE 4.36 T6 Corrected HELIOS recovery (ng/cm^2 leaf) based on an applied dose of 0.6 $ml/100m^3$

Treatment	BO	BI	MO	MI	TO	TI
#1	10.5	6.1	8.7	5.7	5.1	2.3
#2	10.5	6.3	6.2	3.1	5.2	3.7
#3	19.2	12.9	15.2	8.4	9.8	7.3
#4	10.6	5.6	9.3	4.6	6.9	3.2

The pattern of recovery was similar for all treatments (FIGURE 4.35), which was not very surprising given that, at the speeds and volumes tested, the processes by which droplets reached their targets would have been the same. The % recovery for TO-BI excludes recoveries at TI and BO, the hardest and easiest sites to spray, respectively.

FIGURE 4.35 T6 The % total recovery for each site and treatment (#1 - #4).

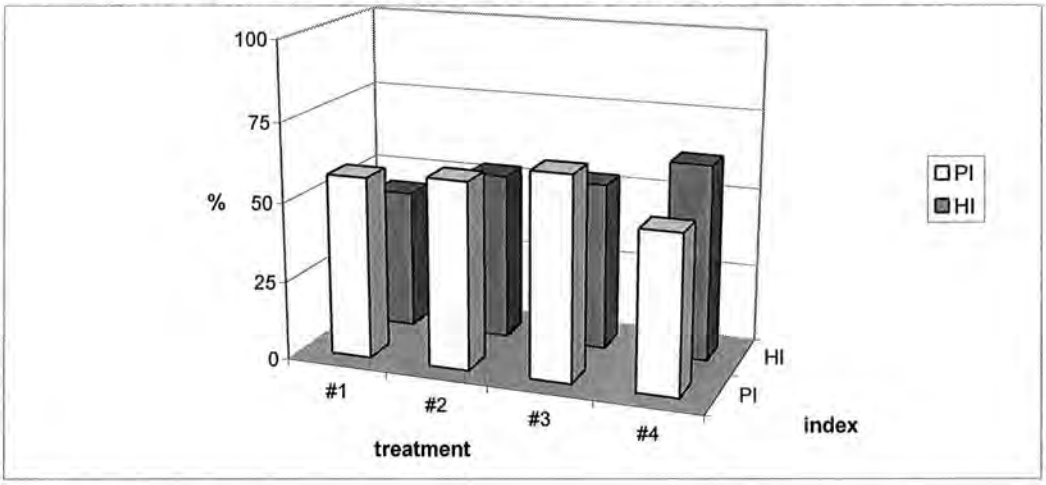


The PI and HI were similar in all treatments (TABLE 4.37 and FIGURE 4.36) suggesting that air volume / unit canopy was not a major factor in performance.

TABLE 4.37 T6 Corrected HELIOS coverage indices.

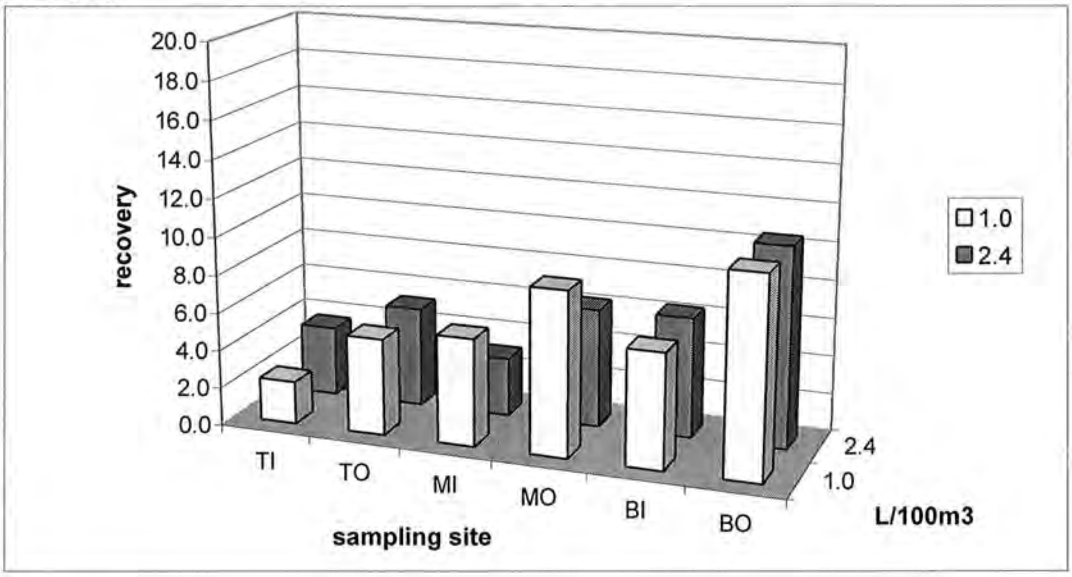
Treatment	Volume ($L/100m^3$)	Total B:M:T (ng/cm^2)	PI	HI
#1	1.0	38.3	58	44
#2	2.4	35.1	59	53
#3	2.7	72.8	65	53
#4	2.0	40.3	50	62

FIGURE 4.36 T6 The effects of speed and volume on PI and HI.



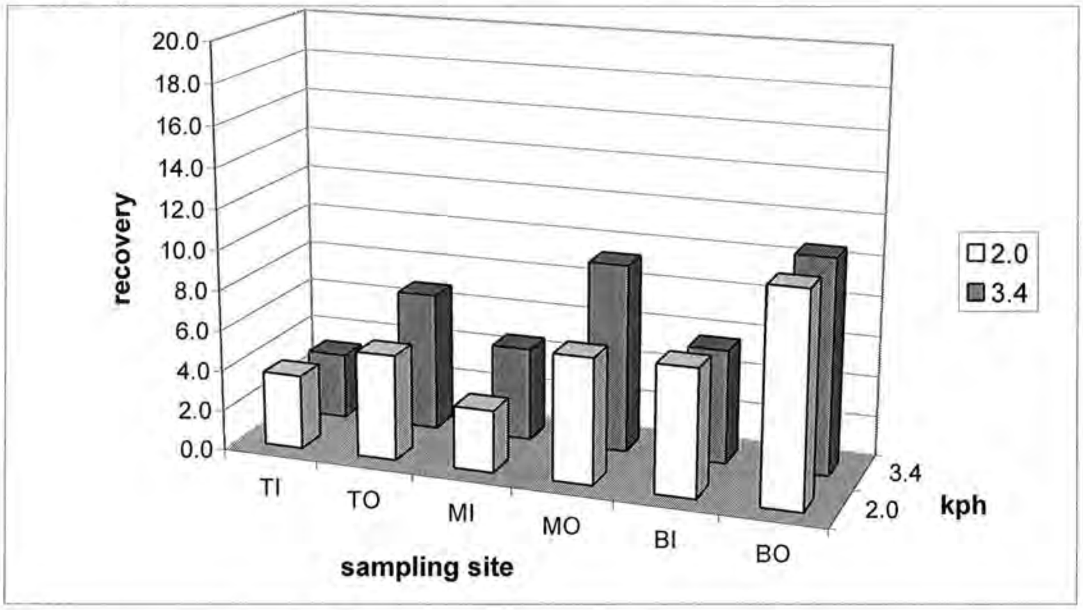
At the medium speed of 3.4 kph recovery at the lowest spray volume of 1.0 L/100m3 was only slightly better than the higher volume (FIGURE 4.37).

FIGURE 4.37 T6 The effects of spray volume on recovery at medium speed (3.4 kph).



At medium volume the recovery in the top part of the outer canopy (TO and MO) was slightly better at medium speed than slow speed (FIGURE 4.38). This again suggests that coverage in the top of canopies is achieved more by drift than air displacement.

FIGURE 4.38 T6 The effects of speed on recovery at medium volume (2.0-2.4 L/100m^3).



The results suggest that at low volumes the air volume / unit canopy, the basis for the air displacement concept, is not a major factor determining coverage. In this trial all volumes were relatively low, although there was a wide range of nozzle and droplet sizes, and yet the recoveries were amazingly similar.

4.7 Double-sided low-profile sprayer with novel conveyor (DS SF45 X)

Double-sided spraying offers considerable savings in tractor costs and reduced soil compaction compared with single-sided spraying. The DS sprayer tested was reported to have a significantly higher air output than a comparable SS sprayer due to improved air inlet and outlet design. The air was ducted to each outlet and combined a short tower with short under-canopy shutes (see FIGURE 4.39). It appeared to combine low speed air in the centre with high speed air at the top and bottom. The treatment matrix is given in TABLE 4.38 below. Two additional treatments, at very low volume and at very high speed were added to the standard matrix.

TABLE 4.38 T11 Treatment matrix plan

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
			#4 2.0 kph 2.0 L/100m^3 1089 L/ha		**SLOW SPEED 2.0 kph**
Treatment **Speed** **Volume/canopy** **Volume/ha**	#8 3.4 kph 0.5 L/100m^3 249 L/ha	#1 3.4 kph 1.2 L/100m^3 627 L/ha	#2 3.4 kph 2.0 L/100m^3 1093 L/ha	#3 3.4 kph 3.2 L/100m^3 1716 L/ha	**MEDIUM SPEED 3.4 kph**
			#5 4.8 kph 2.0 L/100m^3 1051 L/ha		**FAST SPEED 4.8 kph**
		#9 5.6 kph 1.2 L/100m^3 660 L/ha			**VERY FAST SPEED 5.6 kph**

FIGURE 4.39 T11 the DS SF45 X sprayer in action.

The Albuz ATR jets and pressures for each treatment are given in TABLE 4.39

TABLE 4.39 T11 Jets and pressures

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
			#4 2.0 L/100m³ 5 Br, 10 Ye 15 bar		**SLOW SPEED 2.0 kph**
Treatment **Volume/canopy** **Jets per side** **Pressure**	#8 0.5 L/100m³ 15 Li 7 bar	#1 1.2 L/100m³ 5 Or, 10 Br 15 bar	#2 2.0 L/100m³ 5 Rd, 10 Or 15 bar	#3 3.2 L/100m³ 15 Gr 15 bar	**MEDIUM SPEED 3.4 kph**
			#5 2.0 L/100m³ 5 Gr, 10 Rd 15 bar		**FAST SPEED 4.8 kph**
		#9 1.2 L/100m³ 5 Rd, 10 Or 15 bar			**VERY FAST SPEED 5.6 kph**

Weather conditions were generally good with almost no wind and generally low temperatures (TABLE 4.40). There were occasional rain showers but none of the treatments or samples was affected. Treatment #1 did have a higher ΔT due to the higher temperature and low humidity.

TABLE 4.40 T11 Application conditions.

Treatmen t No. Date	Average wind speed (m/second)	Wind direction	Temperature (^{o}C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	Nil	N/E	23.3	54	6.0
#2	Nil	N/W	18.4	90	1.0
#3	Nil	N	16.5	91	1.0
#4	Nil	N/W	20.0	70	3.5
#5	Nil	N/W	22.0	65	4.5
#8	Nil	NNE	21.9	71	3.5
#9	Nil	NNE	19.6	84	2.0

The HELIOS rates and doses used are given in TABLE 4.41. Treatment #3 at the higher volume had the lowest dose applied, slightly below the target of 30 ml / hectare.

TABLE 4.41 T11 HELIOS dosage applied

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#1	1.2	6.0	37.6	0.705
#2	2.0	3.0	32.8	0.615
#3	3.2	1.5	25.7	0.483
#4	2.0	3.0	32.7	0.613
#5	2.0	3.1	32.1	0.601
#8	0.5	12.0	29.9	0.560
#9	1.2	6.0	39.6	0.742

The corrected HELIOS recovery, PI and HI for each treatment are given in TABLES 4.42 and 4.43. Treatments #3 and #5 had the highest recoveries. Treatments #3, #4, #5 and #9 had higher PI, but lower HI.

TABLE 4.42 T11 Corrected HELIOS recovery based on an applied dose of 0.6 $ml/100m^3$

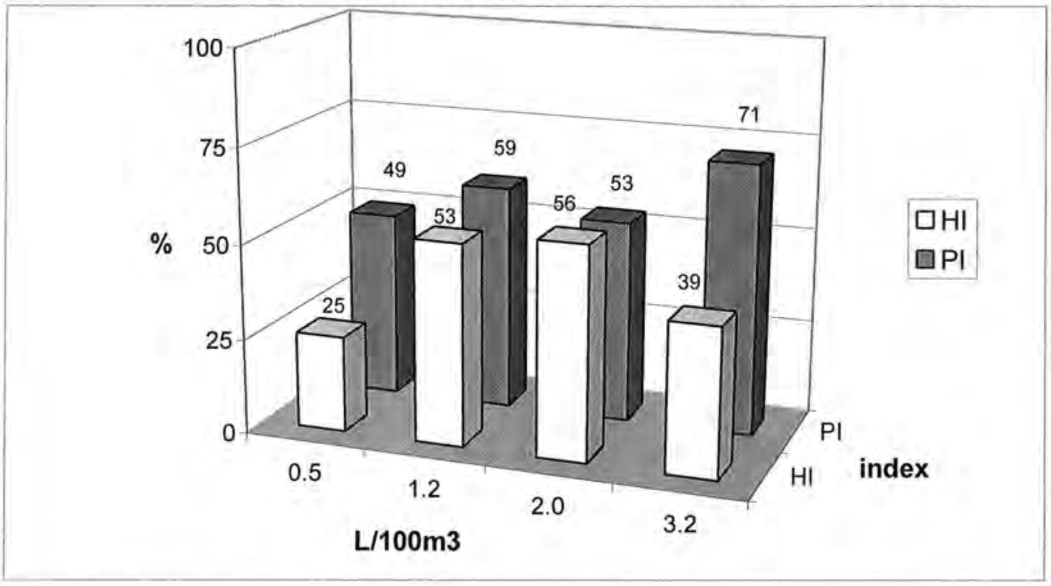
Treatment	BO	BI	MO	MI	TO	TI
#1	39.3	23.4	39.2	29.0	24.5	8.8
#2	94.5	38.9	58.2	42.3	48.9	26.2
#3	149.1	80.7	91.6	87.5	50.6	39.6
#4	76.0	39.7	40.5	47.0	21.2	17.9
#5	109.8	110.4	97.0	64.7	55.5	39.2
#8	60.8	23.2	32.8	18.1	11.1	10.2
#9	111.6	76.6	56.8	48.2	21.3	19.7

TABLE 4.43 T11 Corrected HELIOS coverage indices.

Treatment	Volume ($L/100m^3$)	Total B:M:T (ng/cm^2)	PI	HI
#1	1.2	164.2	59	53
#2	2.0	308.9	53	56
#3	3.2	499.1	71	39
#4	2.0	242.3	76	34
#5	2.0	476.6	82	43
#8	0.5	156.3	49	25
#9	1.2	334.2	76	22

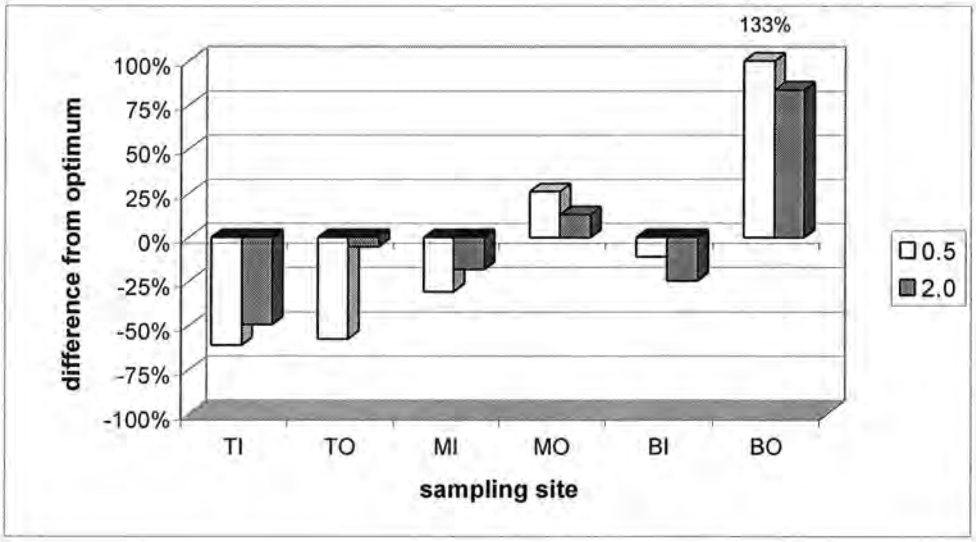
As shown in FIGURE 4.40 at medium speed (3.4 kph) the PI increased with volume. In contrast HI was highest at 1-2 $L/100m^3$. This would appear to confirm the trend that higher volumes, even at only 50% of POR, increase PI by increasing BI because of runoff from the middle of the canopy.

FIGURE 4.40 T11 The effects of volume (0.5 – 3.2 L/100m^3) on the Penetration (PI) and Height (HI) Indices at medium speed (3.4 kph).



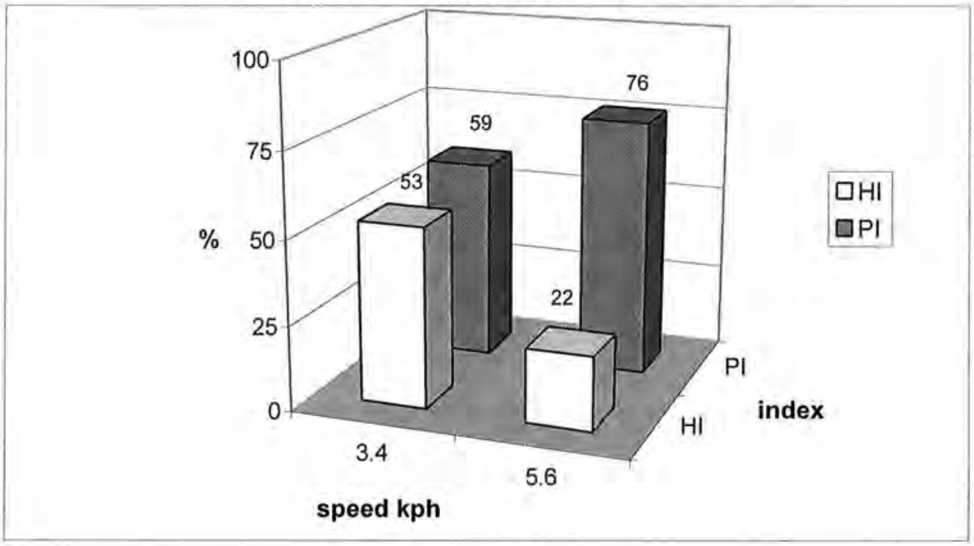
A comparison of spray distribution for 0.5 and 2.0 L/100m^3 at medium speed illustrated in FIGURE 4.41 surprisingly showed that with the lower volume (#8) the coverage was worse in the top of the canopy. This would suggest that in #8 the smaller droplets produced by the Albuz ATR Lilac nozzles were either too small to be collected by the target, or had too little momentum to reach the top of the canopy. At 7 bar the Lilac nozzles would produce a VMD of about 92 μm, much lower than Green, Red or Orange at 15 bar. The higher volume (#2) gave excellent even coverage across the core zone (TO-MO-MI-BI) but still performed poorly overall by overdoing BO and underdosing TI.

FIGURE 4.41 T11 The effects of spray volume (0.5 and 2.0 L/100m^3) on Distribution at medium speed (3.4 kph).



At low volume the speed had a large effect on PI and HI as shown in FIGURE 4.42. At 5.6 kph (#9) the PI was 76% compared with 59% at 3.4 kph (#1). At the higher speed HI was down to 22%. This again is consistent with the idea that droplets from hollow cone jets need time to be carried in the airstream to the top of the canopy. At 5.6 kph the sprayer is only beside an individual tree (4m wide) for 2.5 seconds, and much of the spray is recovered at the bottom of the tree.

FIGURE 4.42 T11 The effects of speed (3.4 and 5.6 kph) on PI and HI at low volume (1.2 L/100m^3).



At medium volume the effect of speed was more variable as shown in FIGURES 4.43 and 4.44. At the lower (2.0 kph) and higher (4.8 kph) speeds PI was higher and HI lower. This is explained by two different processes. At low speed PI increases because of the air displacement process, ie. there is sufficient air per cubic metre of canopy to fill the bottom of the canopy with droplets. This particularly increases MI, increasing PI and reducing HI. At high speed the air displacement effect reduces but is counterbalanced by a reduction in transport of droplets to the top, with more droplets drifting or running off to MO and BI.

FIGURE 4.43 T11 The effects of speed (2.0 – 4.8 kph) on PI and HI at medium volume (2.0 L/100m^3).

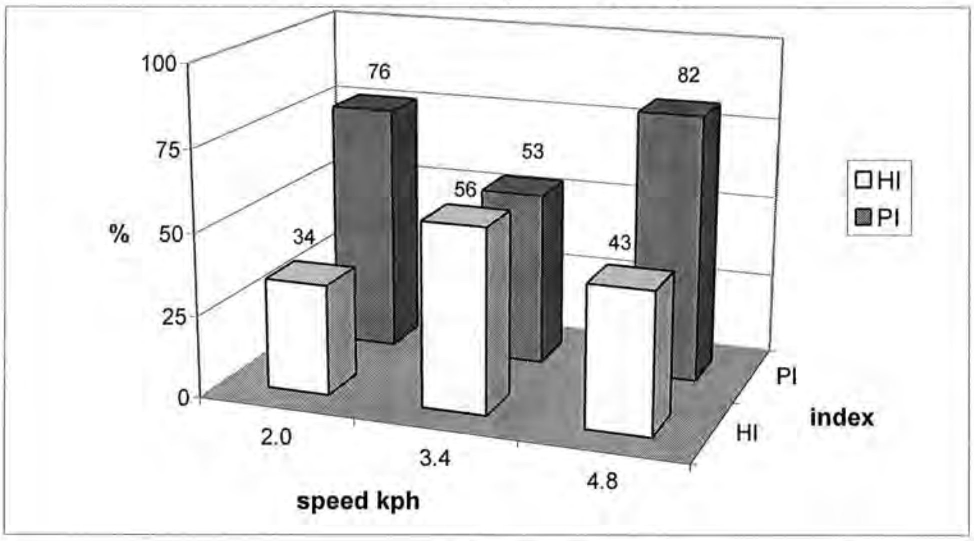
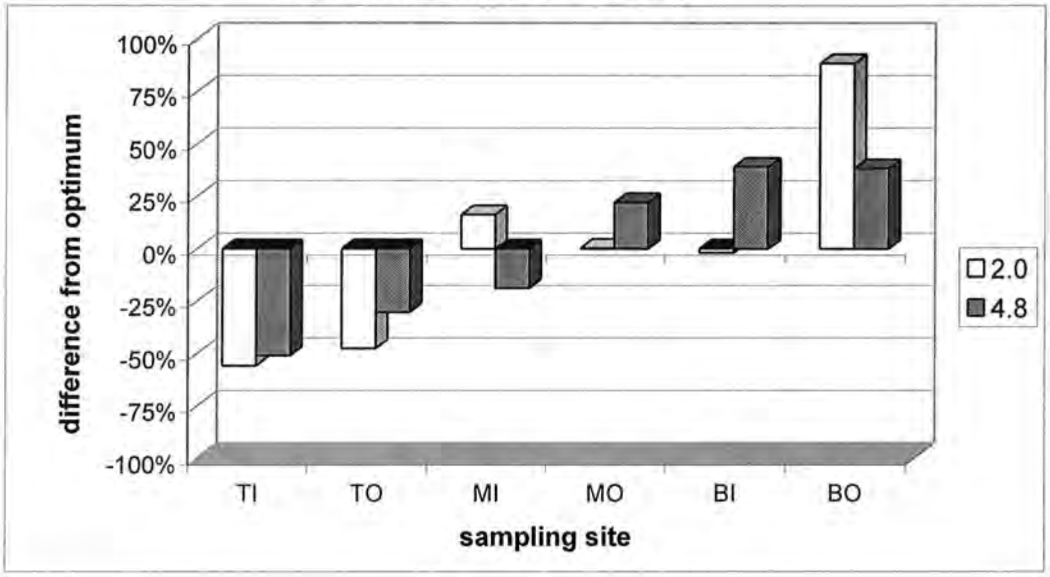


FIGURE 4.44 T11 The effects of speed (2.0 and 4.8 kph) on Distribution at medium volume (2.0 L/100m³).



This sprayer achieved impressive results across the core of the tree, even at high speed. However like other LP sprayers it still tended to underdose TI and overdose BO. Anecdotal evidence suggested that droplet size was critical to the performance of this machine and this was supported by the very poor result with the Albuz ATR Lilac nozzles.

The large number of nozzles each side give great flexibility in application. In retrospect it would have been interesting to try this machine with all the lower shute nozzles switched off. The manufacturer suggests that the high speed airstream from the lower shute entrains air from the centre of the conveyor, drawing spray laden air into the canopy. This effect is not visible but if it does occur it should work even without spray from the shute.

4.8 T12 Double-side airshear sprayer with modified tower (DS CF2T)

A modified airshear sprayer belonging to Sahara Farms, with a higher air output than the DS CF T1 tested in Arbuckles 344, was tested in Gowens 344. The sprayer was tested at medium speed with 4 application volumes ranging from 0.5 L/100m^3 up to 2.4 L/100m^3 and at high speed with one very low volume rate. This was to try and assess the effectiveness of higher air volumes on the airshear performance and to confirm anecdotal reports of good effectiveness at much higher speeds than those used for general airblast spraying. The treatment matrix is given in TABLE 4.44 below.

TABLE 4.44 T12 Trial setup

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
Treatment **Speed** **Volume/canopy** **Volume/ha**	**#2** 3.4 kph 0.5 L/100m^3 250 L/ha	**#3** 3.4 kph 0.7 L/100m^3 360 L/ha	**#1** 3.4 kph 0.9 L/100m^3 459 L/ha	**#5** 3.4 kph 2.4 L/100m^3 1284 L/ha	**MEDIUM SPEED 3.4 kph**
Treatment **Speed** **Volume/canopy** **Volume/ha**	**#4** 5.0 kph 0.5 L/100m^3 250 L/ha	x	x	x	**FAST SPEED 5.0 kph**

The sprayer had a double-sided tower structure with two heads per side. Flow rate was adjusted by a lever on a dial to the required flow rate per hour. The actual flow rate differed slightly from that given on the dial, so actual measured rates were used (TABLE 4.45).

TABLE 4.45 T12 Flow rates and pressures

	VERY LOW VOLUME	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
Treatment **Volume/canopy** **Flow setting** **Pressure**	#2 0.5 L/100m^3 Set 195 L/hr 1.0 bar	#3 0.7 L/100m^3 Set 280 L/hr 1.0 bar	#1 0.9 L/100m^3 Set 390 L/hr 1.4 bar	#5 2.4 L/100m^3 Set 1000 L/hr 1.0 bar	**MEDIUM SPEED 3.4 kph**
	#4 0.5 L/100m^3 Set 280 L/hr 1.0 bar				**FAST SPEED 5.0 kph**

Weather conditions for the trial were very stable with negligible wind, low temperatures and moderate humidity (see TABLE 4.46 below). The conditions were perhaps a little too still for optimum results with the drift process of the airshear sprayer. Treatment #1 had the highest ΔT.

TABLE 4.46 T12 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (^{o} C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	Nil	E	21.6	48	7.0
#2	Nil	N/NE	20.7	66	4.0
#3	Nil	N/NE	20.0	66	4.0
#4	Nil	E	20.5	63	4.5
#5	Nil	E	20.5	63	4.5

The dosages of HELIOS applied are given in TABLE 4.47.

TABLE 4.47 T12 HELIOS dosage applied

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#1	0.9	12.0	55.1	1.033
#2	0.5	12.1	30.3	0.567
#3	0.7	12.1	43.6	0.817
#4	0.5	12.2	30.5	0.572
#5	2.4	2.9	37.2	0.698

The HELIOS recovery is given in TABLE 4.48 and HI and Pi in TABLE 4.49.

TABLE 4.48 T12 Corrected HELIOS recovery based on an applied dose of 0.6 $ml/100m^3$

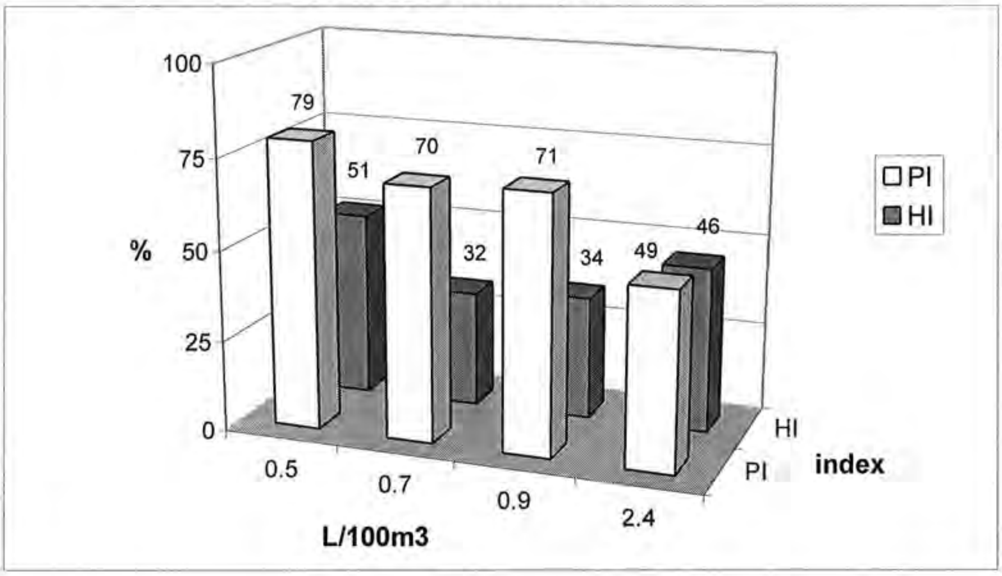
Treatment	BO	BI	MO	MI	TO	TI
#1	57.7	35.5	45.2	29.9	14.0	17.7
#2	98.3	43.5	75.7	62.4	22.6	50.1
#3	85.5	48.4	62.4	45.3	19.7	23.2
#4	88.5	50.7	124.8	44.0	55.3	18.1
#5	63.4	37.4	76.4	37.3	34.7	11.3

TABLE 4.49 T12 Corrected HELIOS coverage indices.

Treatment	Volume ($L/100m^3$)	Total B:M:T (ng/cm^2)	PI	HI
#1	0.9	200.0	71	34
#2	0.5	352.6	79	51
#3	0.7	284.5	70	32
#4	0.5	381.4	42	53
#5	2.4	260.4	49	46

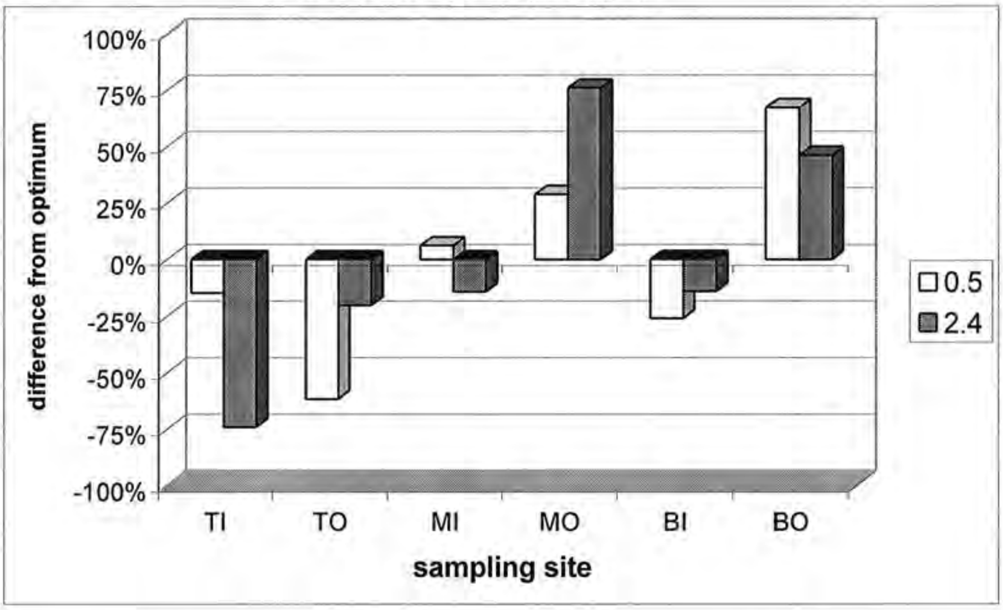
The PI was high (>70%) for low volumes of 0.5 – 0.9 L/100m^3 but fell dramiatically at 2.4 L. This is because MO increases at the expense of TI. It highlights the fact that the airstream cannot carry the larger droplets to the top of the tree where they could drift into the canopy, but that the droplets drop out half way impacting on the outside of the canopy. Because the volume of 2.4 L/100m^3 is still well below runoff there is little redistribution to BO or BI which occurs with high volumes.

FIGURE 4.45 T12 Effect of spray volume (0.5 – 2.4 L/100m^3) on PI and HI at medium speed (3.4 kph).



A more detailed analysis of the distribution shown in FIGURE 4.46 shows that the BI and MI sites have about 17% each of the dose applied, but the BO and MO sites are overdosed at the expense of TO and TI. At the very lowest volume of 0.5 L/100m^3, BO is highest and MO lowest, whereas at 2.4 L it is MO which is highest and TI lowest.

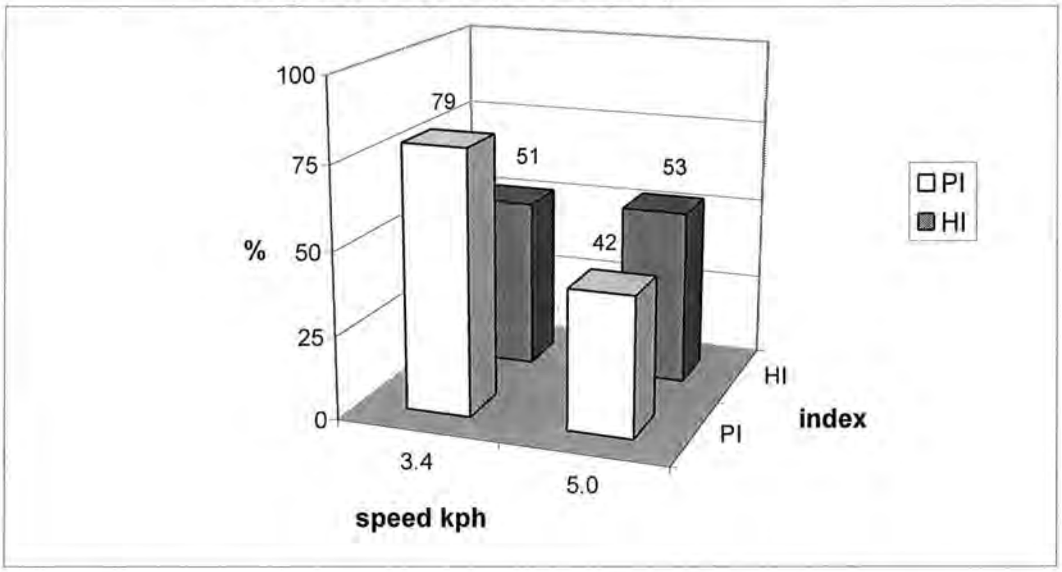
FIGURE 4.46 T12 Effect of spray volume (0.5 and 2.4 L/100m^3) on Distribution at medium speed (3.4 kph).



At very low volume (0.5 L/100m3) the PI fell from 79% at 3.4 kph to 42% at 5.0 kph (FIGURE

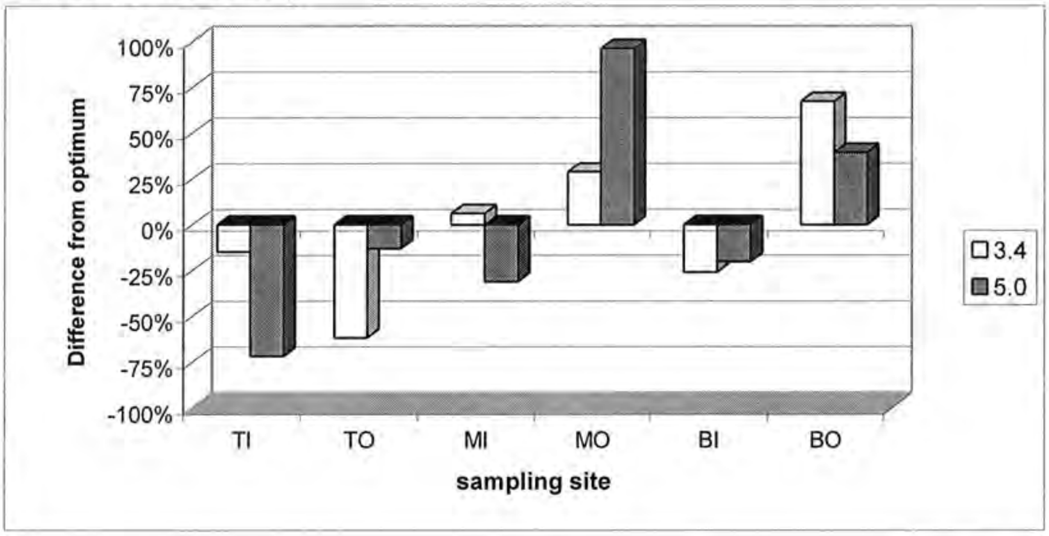
4.47). This highlights the importance of the airstream in throwing droplets above the canopy so that they can drift under GRAVITY to their target. Where droplet size is small and speed high, the sprayer has moved on before droplets reach their target, which is in reality ABOVE the canopy.

FIGURE 4.47 T12 Effect of speed (3.4 and 5.0 kph) on PI and HI at very low volume (0.5 L/100m³).



In 3 out of 5 treatments with this sprayer TI had higher recovery than TO perhaps suggesting that droplets were somehow captured within the canopy before settling onto leaves, whereas on the outside these were lost. These 3 treatments were all at the medium speed (3.4 kph) and lower volumes (eg. FIGURE 4.48).

FIGURE 4.48 T12 Effect of speed (3.4 and 5.0 kph) on Distribution at very low volume (0.5 L/100m³).



The results highlighted the advantages of airshear technology producing a narrow spectrum of small droplets which generally DRIFT to their target. As outlined previously the high speed air creates droplets with high kinetic energy and throws them above the canopy. If they are very small they will penetrate the inside canopy well but are also likely to be prone to off-target drift. If they are very large they will drop rapidly under gravity depositing predominantly on the outside lower part of the canopy.

Droplet size is determined by airspeed and flow rate. However there is limited grower information on droplet size for airshear sprayers. It appears from our trials that the volume of 1-2 L/100m3 gave the best results in terms of even deposit.

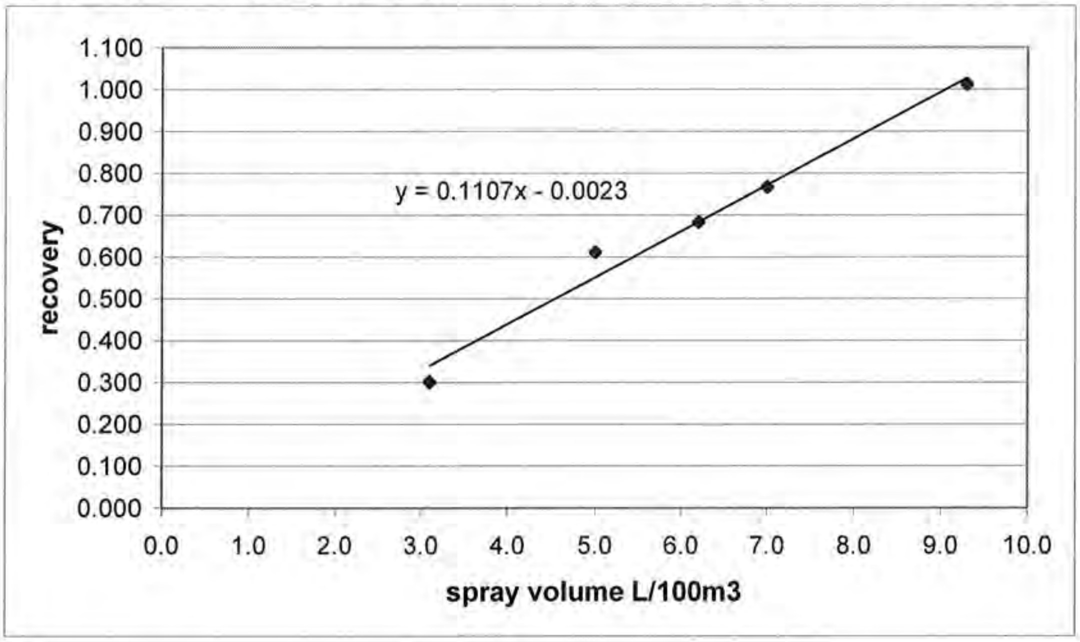
5 OTHER STUDIES

5.1 T1-T5 Runoff to soil

For trials T1 – T5 the runoff to soil was measured using absorbent paper strips placed under the trees. For each treatment 4 trees were sampled, each using two strips. The strips were placed close to the trunk with one strip along the row and another across the row. The results for each trial are plotted below against spray volume applied, not against dose of Helios applied. There are therefore large differences in values between trial T1, where Dilute spraying was used, and T2-T5 where Concentrate spraying was used. However the general trends are the same – the more you apply the more goes on the soil.

The results for T1 are nearly linear in the range 3.1 – 9.3 L/100m^3 (FIGURE 5.1).

FIGURE 5.1 T1 Dilute SS SF45 hf under tree recovery in μL Helios/cm^2.



However for the lower volume sprays in T2 – T5 there is a consistent increase in recovery for the spray volumes below 1.0 L/100m^3 (FIGURES 5.2, 5.3, 5.4 and 5.5). This may reflect the increased risk of drift from smaller droplets but in T2 at least the same droplet spectrums were expected.

As expected, where there were more than one treatment at a particular volume the highest recovery on the soil corresponded to the applications at highest speed. At higher speed one would expect less penetration of the canopy and greater off-target losses. However these differences were small and unlikely to be significant. The dominant factor was obviously application volume.

FIGURE 5.2 T2 Concentrate SS SF45 hf under tree recovery in μL Helios/cm².

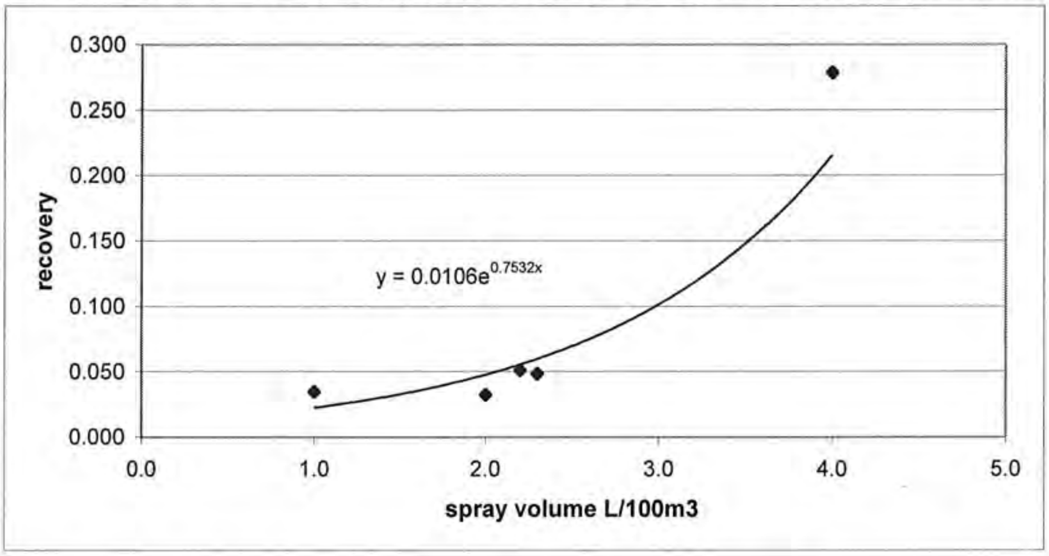
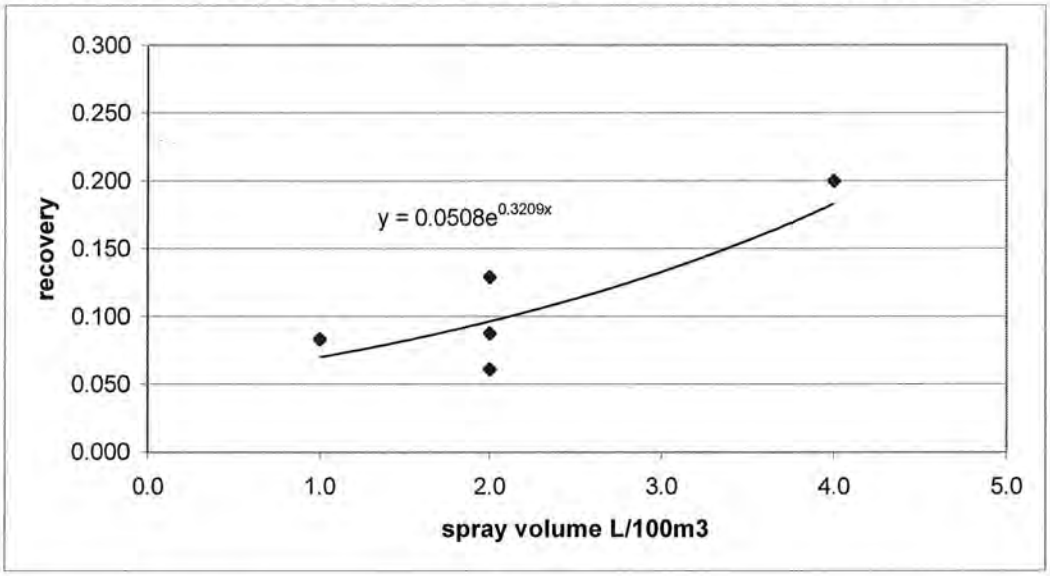


FIGURE 5.3 T3 DS SF35 + 2TF under tree recovery in μL Helios/cm².



In FIGURE 5.3 the highest recovery at 2.0 L/100m^3 corresponded to the treatment at high speed, namely 4.8 kph.

FIGURE 5.4 T4 DS CF T1 under tree recovery in µL Helios/cm².

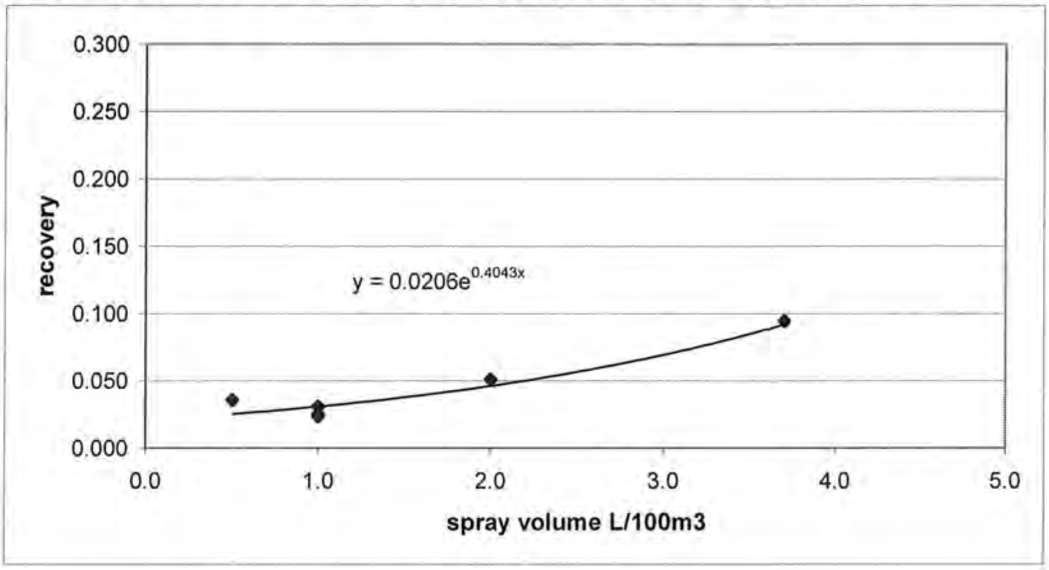
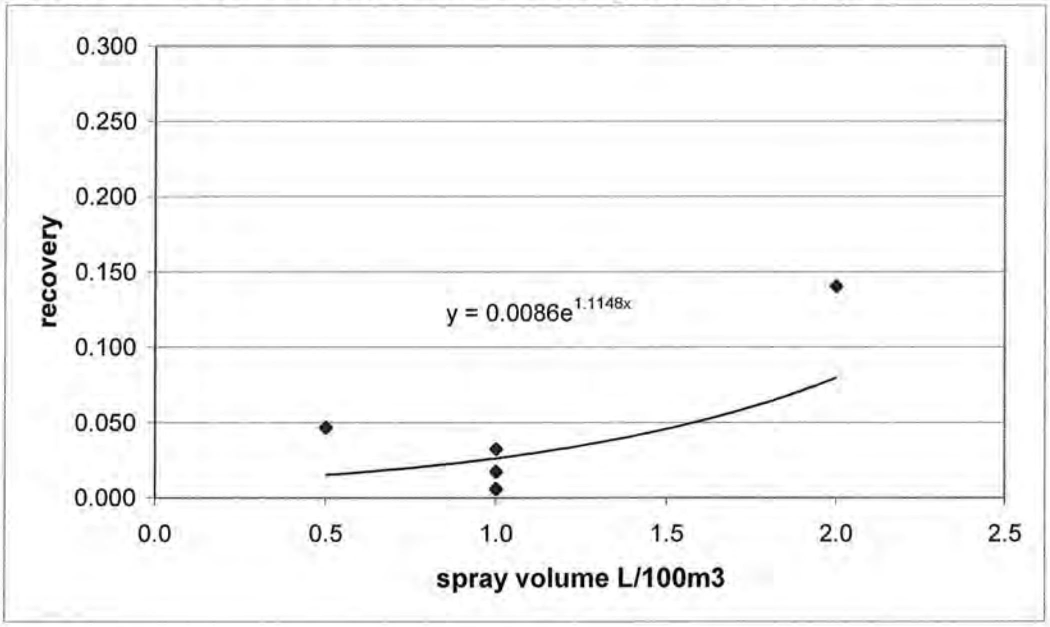


FIGURE 5.5 T5 DS 8TF under tree recovery in µL Helios/cm².



In FIGURE 5.5 the highest recovery at 1.0 L/100m^3 corresponded to the treatment at high speed, namely 4.8 kph. Given the apparently very poor coverage achieved with this sprayer it was surprising not to see higher levels of recovery on the ground. It seems likely that most of the spray actually fell in the interrow rather than under the canopy.

The soil recovery data generally suggest that in the range of 1-10 L/100m^3 recovery is proportional to volume applied. At volumes below 1 L/100m3 there is an increase in recovery, possibly due to poorer capture of smaller droplets.

5.2 T14 Spray distribution

QDPI literature from the 1980's (eg. Behncken, 1983, Banks *et al.*, 1990) recommended that in tree crops 60% of the spray should be targeted at the Top of the canopy, with 30% in the Middle and 10% at the bottom (T:M:B = 60:30:10). Work by Broadley *et al.* (1993a & b) cast some doubt on this and concluded that in macadamias a distribution of 20:30:50 gave better results. For the early trials we had used 30:50:20 based on the argument that this better reflected the canopy volumes in the different portions of the tree and minimised off-target losses where there was variation in tree height.

This series of treatments looked at the effect of changing the distribution while keeping all other variables constant (TABLE 5.1). Differences in distribution were achieved by using double or triple nozzles as required. All treatments were applied at Low speed of 2.0 kph with 2.0 L/100m^3 of spray from 10 Albuz ATR Orange jets using the SS SF40 hf sprayer.

TABLE 5.1 T14 Trial setup

	LOW VOLUME	MEDIUM VOLUME	HIGH VOLUME	
Treatments T:M:B		**#1** 60:30:10 **#2** 30:40:30 **#3** 80:10:10		
Volume/canopy	x	2.0 L/100m^3	x	**LOW SPEED 2.0 kph**
Volume/ha		1080 L/ha		
Jets per side		10 Or		
Pressure		15 bar		

Application conditions for all treatments were good with minimal wind, low temperatures, low humidity and ΔT below 10 (TABLE 5.2).

TABLE 5.2 T14 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (^{0} C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	Nil	SE/SW	16.8	46	6.0
#2	0.3	SW/W	18.2	45	6.5
#3	Nil	SE	19.4	40	7.0

The same mix of spray was used for all three treatments.

TABLE 5.3 T14 HELIOS dosage applied

Treatment No.	Calculated Spray volume (L/100m^3)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose (ml/100m^3)
#1 #2 #3	2.0	6.3	68.0	1.276

The Helios recovery for each treatment is given in TABLE X and following graphs. The results were similar but surprising. There was a consistent trend that the recovery at the Top of the tree decreased as the distribution directed to the top increased. This appears counter-intuitive.

TABLE 5.4 T14 Corrected HELIOS recovery (ng/cm^2 leaf) based on an applied dose of 0.6 ml/100m^3

Treatment	BO	BI	MO	MI	TO	TI
#1 60:30:10	15.6	13.8	10.1	4.8	5.3	3.6
#2 30:40:30	13.3	11.9	9.4	6.1	6.1	4.6
#3 80:10:10	15.5	12.9	8.3	3.5	4.0	2.8

TABLE 5.5 T14 Corrected HELIOS coverage indices.

Treatment	Volume (L/100m^3)	Total B:M:T (ng/cm^2)	PI	HI
#1 60:30:10	2.0	53.2	72	30
#2 30:40:30	2.0	51.4	78	42
#3 80:10:10	2.0	47.0	69	24

FIGURE 5.6 T14 The effects of vertical spray distribution on overall recovery at Top, Middle and Bottom.

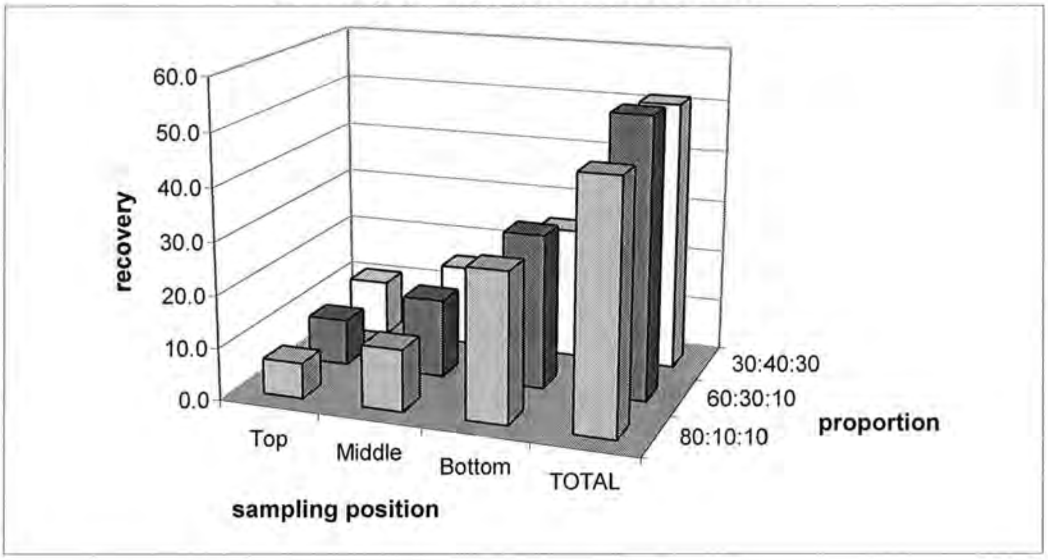
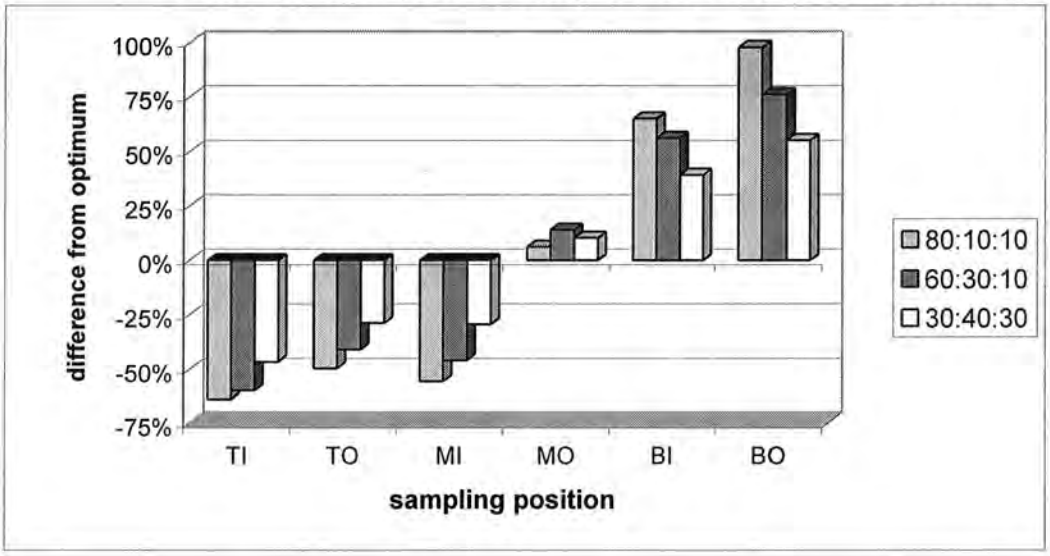


FIGURE 5.7 T14 The effects of vertical spray distribution on the Difference from optimum (17% of spray in each site) at each sampling site.



Compare these results with the results of T9 where the same jets (Albuz ATR Green) and speed (2.0 kph) and a similar volume (1.8 L/100m^3) were applied. The 30:50:20 distribution produced a more even distribution even up to TO but with a large drop in TI.

FIGURE 5.8 T9 The effects of 30:50:20 vertical spray distribution on the Difference from optimum (17% of spray in each site) at each sampling site.

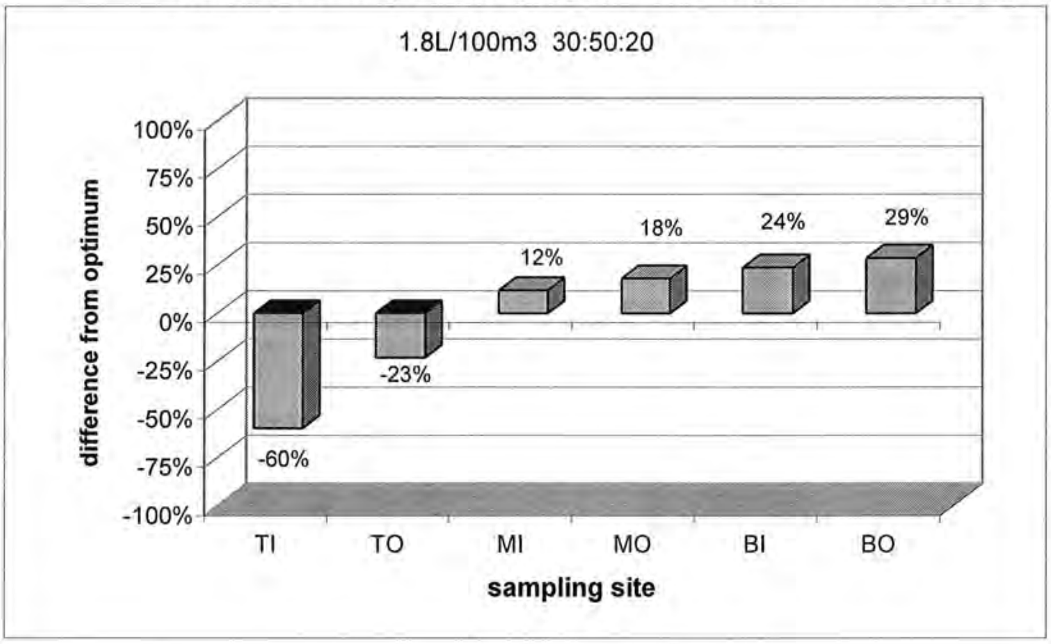
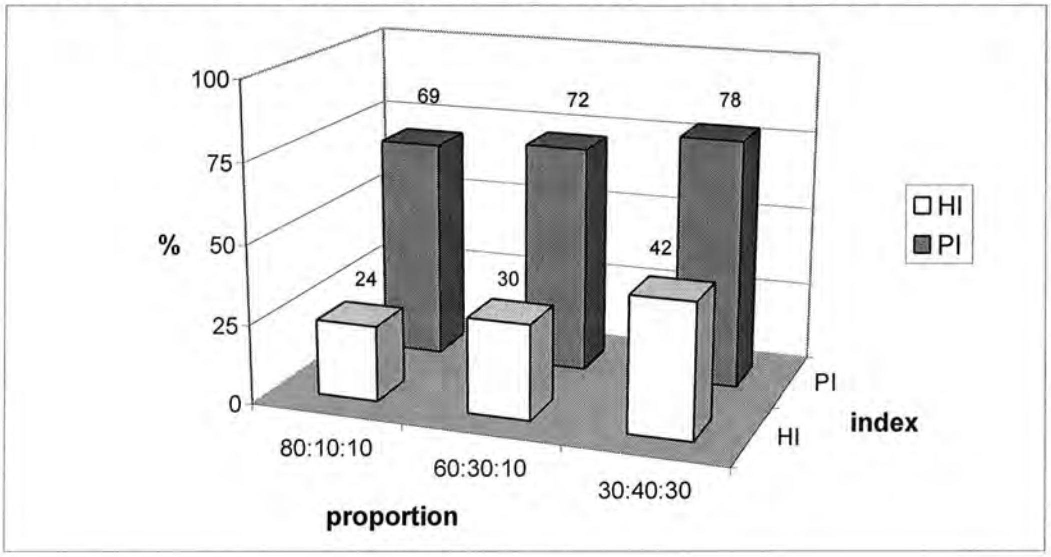


FIGURE 5.9 T14 The effects of vertical spray distribution on the PI and HI.



5.3 T8 Water-sensitive papers (WSP)

The Helios recovery method of assessment has several drawbacks, as outlined in Section 2.1, and is of no use to the individual grower. We therefore determined to compare the results achieved with two very different droplet sizes using Helios, visual assessment using water-sensitive paper[1] (WSP) and analysis using an image analyser. FIGURE 5.10 shows how the WSP was placed close to a comparable leaf which was also sampled for Helios recovery.

The tractor speed and spray volumes were adjusted so that the coverage of the WSP at BO still permitted the counting of individual droplets. With the hollow cone jets this necessitated the use of Brown Albuz ceramic hollow cones at 4.8 kph and 15 bar, giving 30% of spray volume in the 0-70 μm range and 69% in the 70-250 μm range. This treatment with a low droplet size was compared with spray applied using Turbodrop air induction nozzles. The air induction nozzles produce a very large but unknown droplet size.

FIGURE 5.10 This photograph shows how the water-sensitive papers were attached close to a comparable leal analysed for Helios recovery.

Two treatments were applied with 20 ml Helios / 100L as indicated in TABLE 5.6.

TABLE 5.6 Treatment numbers and details

	V.VERY LOW VOLUME	VERY LOW VOLUME	
Treatment	**#1**	**#2**	
Volume/canopy	0.34 L/100m^3	0.48 L/100m^3	**FAST**
Volume/ha	184 L/ha	254 L/ha	**SPEED**
Nozzle type	Albuz ATR	Turbodrop	**4.8 kph**
Size	8 x Brown	3 x Orange + 5 x Green	
Pressure	@ 15 bar	@ 15 bar	

[1] WSP is readily available to growers through Silvan Australia but is relatively expensive.

The trial was carried out in Gowens 344 with the SS SF40 hf sprayer and the Deutz DX7 tractor. Fifteen leaves and associated water sensitive papers were sampled at BO and BI for each treatment. Both the top and bottom leaf / WSP surfaces were assessed. For the Helios assessments recovery was determined for the whole leaf, ie. top + bottom surface. Weather conditions were warm and still with moderate humidity (TABLE 5.7).

TABLE 5.7 Weather conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (°C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	Nil	N/a	27.0	66	5.0
#2	Nil	N/a	30.0	55	7.0

The Helios dosage applied and recovered are given in TABLES 5.8 and 5.9, respectively.

TABLE 5.8 T11 HELIOS dosage applied

Treatment No.	Calculated Spray volume ($L/100m^3$)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose ($ml/100m^3$)
#1	0.35	20	36.8	0.690
#2	0.48	20	50.8	0.953

TABLE 5.9 T11 Corrected HELIOS recovery based on an applied dose of 0.6 ml Helios /$100m^3$.

Treatment	HELIOS recovery		Treatment	HELIOS recovery	
	BO	BI		BO	BI
#1 Albuz	29.8	30.3	#2 Turbodrop	25.3	34.3

At BO the Helios recovery for the Albuz ATR was 118% of that of the Turbodrop. At BI the Helios recovery for the Albuz ATR was 88% of that of the Turbodrop.

In both cases recovery at BI was greater than for BO. One explanation for this is that the canopy air displacement process was almost working at 2.0 kph with a SS sprayer. The inners got sprayed twice (ie. both passes) but the outers got sprayed only once (spray did not fully penetrate to the opposite side of the canopy). You would expect this effect to be more pronounced with bigger droplets, as is the case above.

The image analysis of droplet numbers and % area covered showed similar trends (TABLE 5.10). However the visual assessment of droplets on WSP proved very time-consuming, difficult and inconsistent. The results from the image analyser proved more consistent. Examples of the coverage as shown by WSP are given in APPENDIX F.

TABLE 5.10 Image analysis of water-sensitive papers on front and back leaf surfaces (n=15 leaves per sample)

droplets per cm^2	Front	BO Back	Avg.	Front	BI Back	Avg.
#1 Albuz	50.9	21.6	36.2	53.2	40.1	46.6
#2 Turbodrop	19.4	7.2	13.3	14.8	8.5	11.6
% area covered	**Front**	**BO Back**	**Avg.**	**Front**	**BI Back**	**Avg.**
#1 Albuz	27.3	4.6	15.9	12.0	7.7	9.8
#2 Turbodrop	40.0	2.9	21.4	16.8	9.2	13.0

At BO the average droplets per cm^2 for the Albuz ATR was 272% higher than the Turbodrop while a BI it was 402% higher. However at BO and BI the average % area covered for the Albuz ATR was only 74-75% of that of the Turbodrop. Thus while the Albuz treatment captured many more droplets, particularly at BI, these covered less area than the Turbodrop droplets.

The Albuz had higher uniformity (back/front) in droplets per cm^2 between the two leaf surfaces with 42 and 75% at BO and BI, respectively, compared with 37% and 57% for the Turbodrop. The difference between the nozzles in terms of area covered was even more marked. The Albuz had higher uniformity (back/front) in % area covered between the two leaf surfaces with 17 and 64% at BO and BI, respectively, compared with 7% and 55% for the Turbodrop. For individual leaves there seemed to be an inverse relationship between coverage on the front and back.

In summary the Turbodrop nozzles gave greater average % area coverage than the Albuz but this was achieved mainly on the front surface with little on the back. The difference between front and back was most evident at BO.

FIGURE 5.11 shows these differences comparing the Helios recovery with the image analyser droplets per cm^2. By dividing the Helios recovery by the number of droplets you can get an estimate of the quantity of Helios per droplet and therefore the droplet size. The results suggest that on average Turbodrop droplets contained about 4 times as much Helios, making them equivalent to a solid droplet 150 μm in diameter.

FIGURE 5.11 Helios recovery vs droplet number for Albuz and Turbodrop nozzles

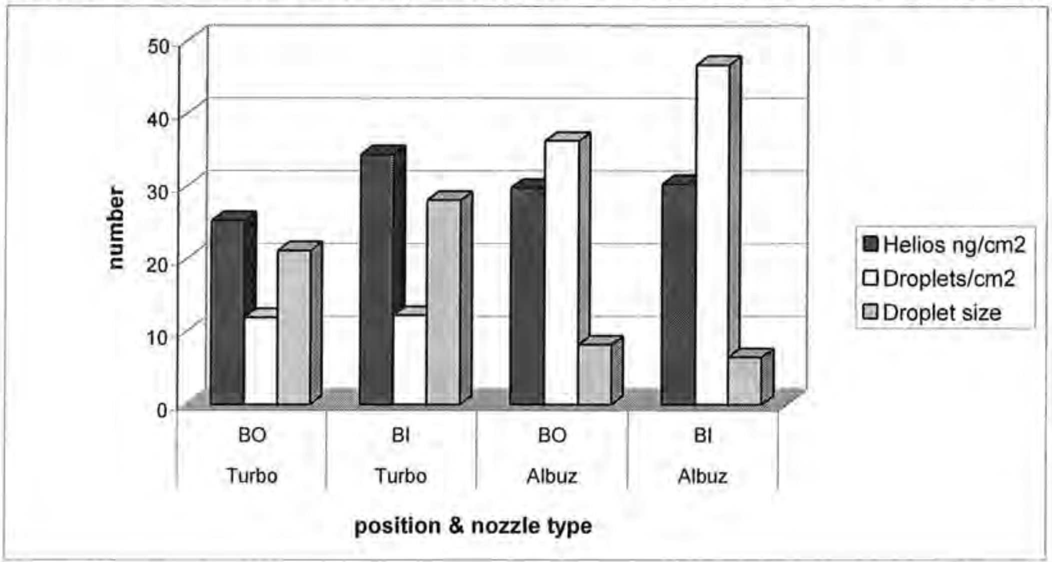


FIGURE 5.11 clearly shows that the average coverage with the Albuz nozzles was very similar at BO and BI. The Turbodrop with its larger droplet size gave higher recovery at BI than BO but this was not reflected in the % area covered (TABLE 5.10).

So how do the Turbodrops achieve greater Helios recovery with less coverage? One reason could be the capability of the image analyser to count and measure droplets which have splattered or smeared. Alternatively it could be something to do with the quantity of air in each droplet distorting the figures. For example a 200 μm air-filled droplet making a 200 μm impact mark on WSP may only contain the equivalent dose of Helios of a 100 μm droplet. This may also explain why the Turbodrops captured at BI appear to be larger than those captured at BO. It is possible that the airstream actually carries larger air filled droplets more effectively than smaller droplets – just as large bubbles float easily in air. If so this could offer another avenue for improving the carriage of pesticide dose to the top of the canopy. Create larger less dense droplets which can be carried more efficiently by a low speed airstream.

The differences between BO and BI for both types of nozzles could have been due to several reasons:

1. TOO MUCH AIR
2. TOO LITTLE AIR
3. More even leaf flutter at BI due to lower airspeed.
4. Double coverage at BI compared with single at BO.
5. Droplets blown past BO. Suggests direct hits less important than drift or gravity.
6. Leaves at BO blown parallel with airstream resulting in less capture surface.
7. Greater effect of gravity and drift inside canopy on BI.
8. Greater gravity drift within canopy due to settlement from MO and MI.

We were unable to fully determine the causes of the differences and also, unfortunately, we were unable to test for recovery at MO, MI, TO and TI in this trial.

5.4 T17 Dipping comparison

The aim of T17 was to try and determine a baseline of recovery against which other treatments could be compared and to further explain the variation in previous test results. Mature leaves of cv. 344 were dipped into a solution of 3.0 ml Helios per 100L and hung up to dry. Fifteen leaves from each of two replicates were then sent for analysis. Three treatments were applied:

1. Leaves were dipped and then hung Right Way Up (RWU) to dry.
2. Leaves were dipped and then hung UpSide Down (USD) to dry.
3. Leaves were dipped, gently shaken and hung USD to dry.

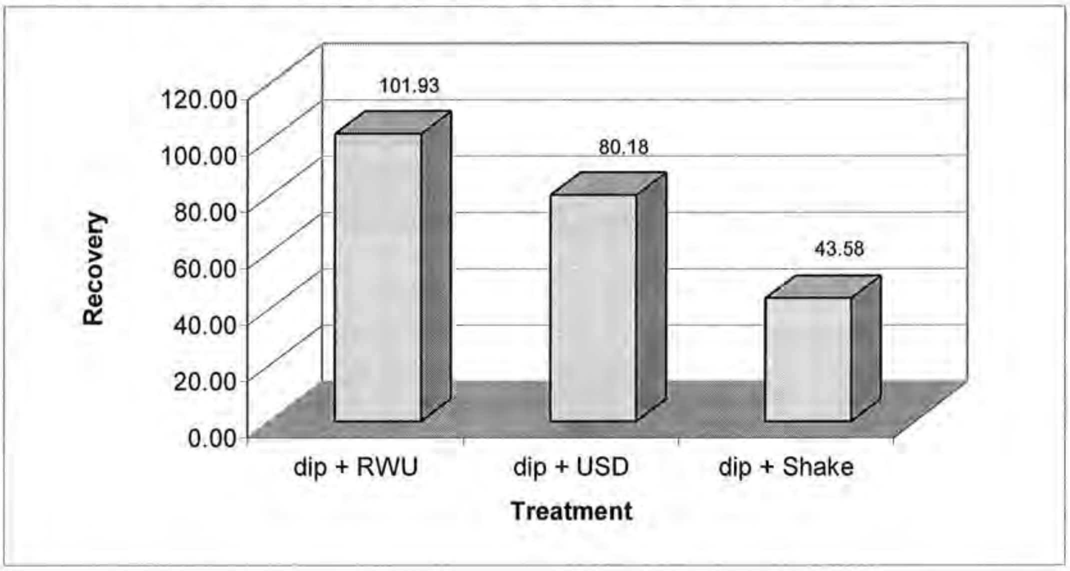
RWU leaves had the leaf tip in the upper position and petiole at the lower position. As an observation Outer leaves generally are oriented in the upright position (RWU) while Inner leaves have a larger proportion of leaves in the upside down position (USD). This characteristic would of course vary widely between varieties.

Corrected recovery was based on spraying to point of runoff @ 6L/100m^3 of canopy, equivalent to 3200L/ha for the Sahara Farms trial block. The corrected recoveries were higher than found in the spray trials.

TABLE 5.11 Corrected recovery for dipped leaves of cv.344.

Treatment of leaves	Corrected Recovery ng/cm2
Dipped and hung RWU	101.9
Dipped and hung USD	80.2
Dipped, shaken and hung upside down	43.6

FIGURE 5.12 Corrected recovery for dipped leaves of cv. 344.



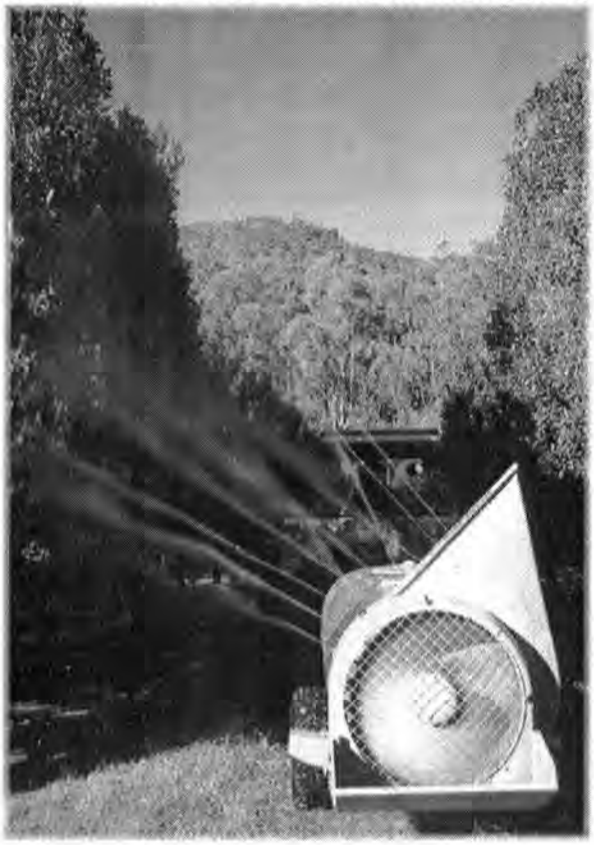
There was a consistent difference between samples hung RWU and those hung USD. This may be due to the leaf tip spike and curling of the leaf near the tip in the USD position increasing runoff. This may explain some of the variation in previous trials where a mix of upright and upside down leaves may have been sampled. Non-shaken leaves could hold twice the residue of shaken leaves, which still appeared fully covered. In the field situation the air-assisted sprayer itself would likely create enough turbulence to shake outer leaves but not inner leaves.

I believe this highlights the importance of runoff drops of spray retained on the leaf. These drops can contain a large volume of water and hence residue. One drop may be equivalent to all of the other residue on the leaf, but would be likely to have much lower immediate biological activity. However such drops may form a reservoir of pesticide which is redistributed by further rainfall or dew.

5.5 T18 solid stream jets – the extreme case

The failure to achieve good coverage at the top of the tree using hollow cone jets led us, at the end of the project to desperate measures – solid stream jets. The solid stream jet produces a solid stream at low pressure, with almost no droplet formation. However at pressures above 10 bar the stream starts to break up. At 15 bar the stream broke into droplets at a distance of anywhere from 0.5 to 1.5 m from the nozzles, as shown in FIGURE X. The droplet cloud looked visually similar to a hollow cone droplet cloud at this pressure. The same setup was tried at 2 speeds, and hence 2 volumes, as shown in TABLE X.

FIGURE 5.13 T18 SS SF40 hf with solid stream jets



The solid stream jets produced high K droplets capable of travelling to a height of 3-4 m, even without air. There was some difficulty adjusting the direction of the nozzles to get even coverage because of the relatively narrow band of coverage from each nozzle and some jets were in fact angled across each other to try to fill in the gaps. Because of the very straight delivery of droplets the top 4 jets of the conveyor were not used. In retorospect we should have tried the same number of jets with top 4 switched "on" and 4 lower ones switched "off".

TABLE 5.12 T18 Treatment numbers and details

	LOW VOLUME	MEDIUM VOLUME	
Treatment **Volume/canopy** **Volume/ha** **Nozzle type** **Pressure**		#1 1.8 L/100m^3 967 L/ha 10 x D1.5 solid stream @ 15 bar	**SLOW SPEED 2.0 kph**
Treatment **Volume/canopy** **Volume/ha** **Nozzle type** **Pressure**	#2 0.9 L/100m^3 456 L/ha 10 x D1.5 solid stream @ 15 bar		**FAST SPEED 4.2 kph**

This trial was carried out in Gowens 344 with the SS SF40 hf sprayer and the Deutz DX7 tractor. Application conditions were good with no wind and moderate humidity (TABLE X).

TABLE 5.13 T18 Application conditions.

Treatment No. Date	Average wind speed (m/second)	Wind direction	Temperature (^{o}C)	Relative humidity (%)	Approx. ΔT for whirling psychrometer
#1	Nil	E/SE	24.9	61	5.5
#2	Nil	E/SE	27.0	66	5.0

The application rates for Helios and subsequent corrected recoveries are given in TABLES X and Y.

TABLE 5.14 T18 HELIOS dosage applied

Treatment No.	Calculated Spray volume (L/100m^3)	HELIOS Mixing rate (ml/100L)	HELIOS Field rate (ml/hectare)	HELIOS Canopy dose (ml/100m^3)
#1	1.8	3.0	29.0	0.544
#4	0.9	6.0	27.4	0.513

TABLE 5.15 T18 Corrected HELIOS recovery based on an applied dose of 0.6 ml Helios /100m^3.

Treatment	BO	BI	MO	MI	TO	TI
#1	53.6	36.6	61.8	33.9	32.1	20.9
#2	60.6	41.0	69.7	37.8	35.9	23.3

The results of the two treatments were very very similar suggesting that neither speed or application volume were critical factors in recovery. Both were at very low volume and despite the large droplet spectrum there was negligible runoff to soil. Runoff from individual leaves was largely captured within the canopy.

The PI and HI are shown in TABLE X and FIGURE X. HI was nearly 60% for both treatments, better than many of the treatments in T2 with the hollow cones.

TABLE 5.16 T18 Corrected HELIOS coverage indices.

Treatment	Volume ($L/100m^3$)	Total B:M:T (ng/cm^2)	PI	HI
#1	1.8	238.9	62	59
#2	0.9	268.3	61	58

FIGURE 5.14 T18 The effects of speed (2.0 and 4.2 kph) and volume (1.8 and 0.9 $L/100m^3$, respectively) on PI and HI.

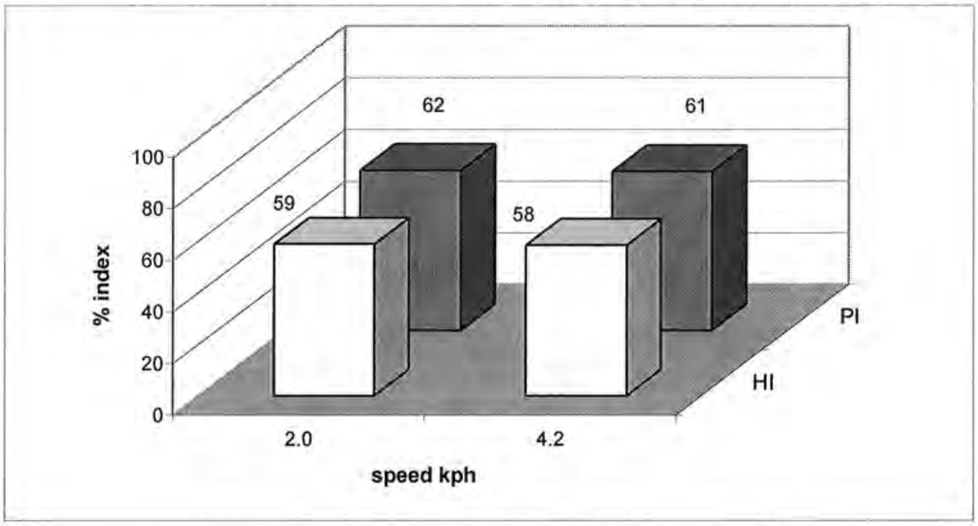
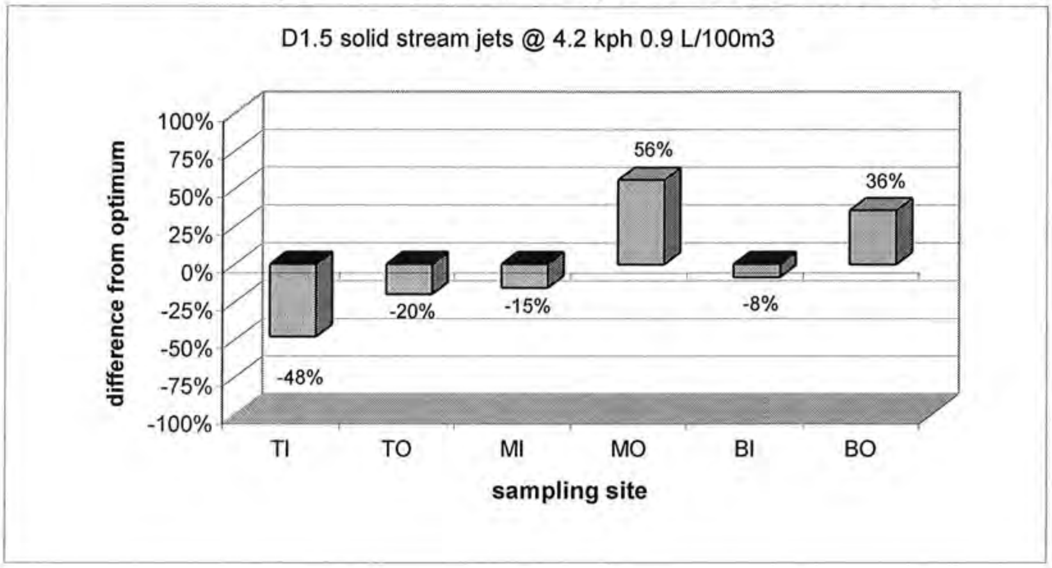
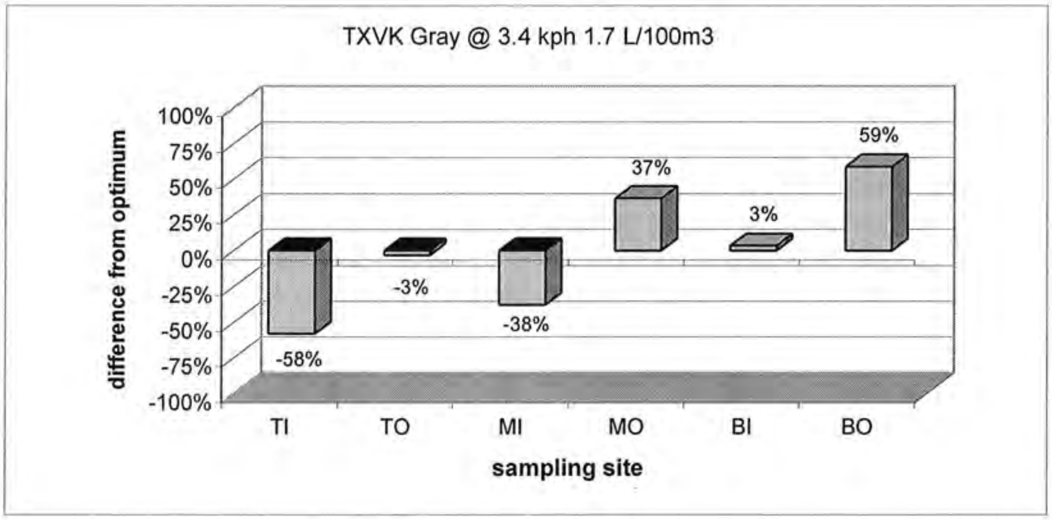


FIGURE X shows the distribution within the canopy. Compare this with the TXVK Gray hollow cones used in T3 also shown below. The solid stream jets delivered more to the middle of the tree (both MO and MI) without increasing recovery at the bottom (particularly BO), even at a faster speed. Because of the narrow width of

FIGURE 5.15 T18 Distribution throughout the canopy at medium speed using Teejet solid stream, D1.5 jets vs Teejet TXVK Gray jets @ 15 bar.





6. DISCUSSION

In his experiments in intensive orchards in the UK Cross (2000) reports that spray liquid flow rate, spray quality and forward speed all had little effect on the mean amounts of spray deposited on leaves per unit amount applied. In simple terms changing the droplet size or tractor speed had no significant effect! Increasing spray volume and reducing speed resulted in less variable deposits but the effects were small. Sounds familiar!

6.1 Droplet movement

Based on the recommendations of years of extension literature to Australian growers, eg. Behncken (1983), Banks *et al.* (1990) and Battaglia *et al.* (1997), most sprayer calibration literature makes three assumptions:

- Up to point of runoff increasing spray volume will increase deposits.
- Changing the distribution of spray volume leaving the sprayer will alter the distribution of deposits in the canopy.
- Increasing air volume (generally by reducing speed) will improve canopy penetration and deposits.

6.1.1 Droplet routes to their targets

Unfortunately the above assumptions ignore the routes by which droplets travel to create deposits in different parts of the canopy. As outlined in Section 3.1.4 droplets contributing to recovery reach their targets by six main routes. The importance of each route will depend on the air volume, turbulence, weather conditions, droplet size, canopy density. To reiterate again, these 6 routes are:

- directly from the sprayer in the fan airstream as the sprayer passes,
- falling under gravity after the sprayer has passed,
- drifting in the general air flow and turbulence after the sprayer has passed,
- runoff down surfaces,
- dripping from surface to surface.
- droplet splatter

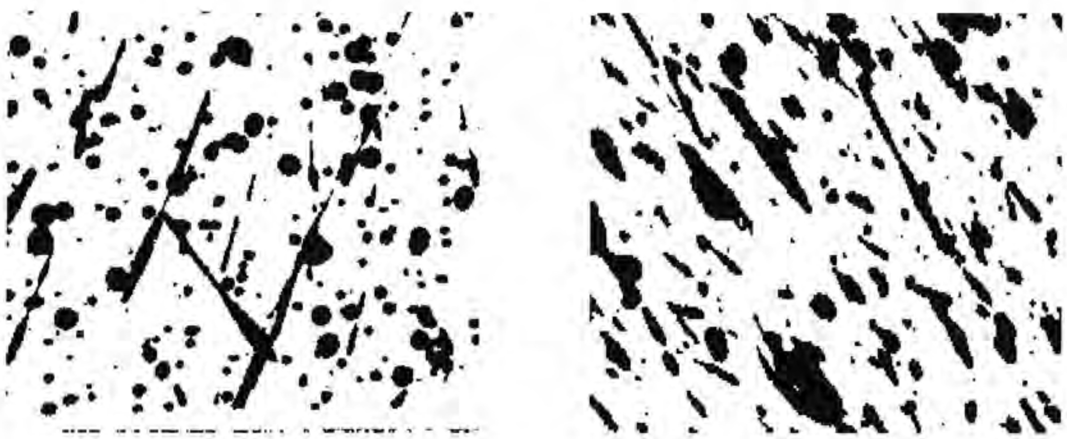
(1) Directly from the sprayer in the fan airstream as the sprayer passes.
The importance of this route will depend on:
- The speed of the airstream.
- The kinetic energy of the droplets.
- The length of time the airstream is adjacent to the tree.
- The ability of the airstream to carry the droplets.
- The density of the canopy and any deflection of the airstream.

(2) Falling under gravity after the sprayer has passed.
All droplets which have not been immediately captured by impacting the target in the airstream will fall under gravity. The importance of this route will depend on:
- The size of the droplets. Larger droplets will fall faster and drift less than smaller droplets.
- The height to which the droplet was propelled.
- The position of the droplet relative to the canopy. Droplets may fall outside the target crop canopy.

(3) Drifting in the general airflow after the sprayer has passed.
Once droplets leave the airstream they are subject to gravity and air movement, or drift. The importance of this route will depend on:

- The size of the droplets. Smaller droplets will fall more slowly and drift further than larger droplets.
- The height to which the droplet was propelled. The higher the droplet the further it can drift.
- The wind above and within the canopy.
- Any turbulence created by the sprayer airstream itself.
- Temperature inversion conditions which may "capture" droplets.

ENLARGEMENT OF WSP SHOWING DROPLETS VIA ROUTES (1), (2) AND (3).



(4) Runoff down surfaces.
If excess spray falls onto a target it will redistribute downwards by gravity. The structure of the tree may result in spray migrating towards the trunk via the branches. Droplets may reach branches, which being immobile and rounded are harder to spray than leaves, by dripping from leaves. The importance of this route will depend on:

- The volume of spray captured by the crop surface. Our estimate is that Application of more than 6 L/100m3 of spray will result in widespread runoff. This may be a positive factor in the control of Husk spot and hard to kill pests such as Latania scale or Felted coccid.
- The surface properties of the target. Waxy surfaces are more prone to runoff.
- The quality of the spray. Addition of wetting agents and/or oils will both affect runoff.

(5) Dripping from surface to surface.
If excess droplets reach an edge they may drop under gravity. This may result in runoff to the soil or redistribution to a lower crop surface. Large droplets which drip are likely to splatter.

(6) Droplet splatter
When a droplet falls onto a target surface two things may happen. The droplet may hit and stay intact or it may splatter. A combination of these is where droplets impact and bounce before final capture. Droplets with greater kinetic energy are more likely to splatter. Analysis of hollow cone droplets captured by water-sensitive papers show little evidence of splatter. However the use of air induction nozzles to create large size air-filled droplets results in significant splatter. Splatter may increase coverage.

ENLARGEMENT OF WSP SHOWING DROPLETS VIA ROUTE (6)

6.1.2 Kinetic energy

Cross (2000) points out that on any airblast sprayer there are 5 operational variables that can be adjusted. These all affect droplet size and movement. The variables are:

(1) The spray liquid flow rate.
(2) The spray quality (droplet size spectrum).
(3) The air volumetric flow rate.
(4) The forward speed.
(5) The number and position of nozzles.

I believe that a sixth critical variable should be added:

(6) The forward kinetic energy of the droplets leaving the nozzles.

There are large differences in kinetic energies between nozzle types. Droplets leave the nozzle at a certain speed and angle to the airstream which affects the ability of the airstream to carry the droplet. The two most extreme types of nozzle are a hydraulic nozzle without a swirl plate (ie. a solid stream nozzle with all droplets travelling in the direction of the airstream) and the CDA spinning disk nozzle (all droplets travelling at 90° to the airstream). For the same droplet size and energy you would expect the hydraulic droplet to travel further because they start with greater forward kinetic energy or momentum.

The ability of air to accelerate or carry droplets will depend on the speed of the air, the individual droplet size and the total volume of water being carried. An analogy would be sediment in a river where faster water can carry more sediment and bigger rocks. To accelerate droplets takes energy. That energy can only come from the airstream itself. The more water you put into the airstream the less energy available to move the air. Given the comparative weights of air and water you would expect that an airstream without spray would travel further than one with spray.

Given the density of air as 1 g/L or 1 kg/m^3, an air output of 75,000 m^3/hr is equivalent to moving 75,000 kg or 75 MT air/hr. Applying 3 L spray/100m^3 canopy at 2 kph would be equivalent to adding 0.04 L spray/m^3 to the air, which is 3000 L/hr or 3 MT/hr. This is not an unrealistic scenario. Applying 6 L/100m^3 would therefore add 6 MT/hr of water. What this means is that as soon as you switch on the sprayer you get a minimum 5-10% reduction in air penetration compared to no spray. Relying on the air to accelerate 3-6 MT of spray into the canopy takes up energy which could be improving droplet carriage. Giving droplets their own momentum as they leave the nozzle eliminates this problem.

What I term "Low K" droplets are accelerated by the airstream the instant they leave the nozzle (eg. droplets from hydraulic hollow cone jets, airshear and CDA spinning disk) and droplets cannot exceed the speed of the airstream. "High K" droplets (eg. droplets from hydraulic solid cones, fan jets and cones without swirls) produce droplets which may exceed the speed of the airstream and deccelerate once they leave the nozzle. Low K droplets may have still individually have high kinetic energy if the airstream is very high speed, eg. for airshear sprayers.

So when is it important to have High K droplets? When the tractor speed is high droplets will only be in the direct airstream for a short time. In this case High K droplets with their own momentum will travel further than Low K droplets. Similarly where air volume or airspeed is low. The further the target from the nozzle the greater the advantages of High K droplets. The implications for hydraulic nozzle setup are that where the target is close to the nozzle and where air volume is high hollow cone nozzles (Low K) will perform best. Where the target is far from the nozzle and where air volume is low solid cone nozzles or cones without swirls (High K) will perform best.

6.1.3 Gravity

All droplets are subject to two forces once they leave the nozzle. These are gravity and air flow. However even within the air flow gravity is at work. The rate at which droplets fall under gravity in still air is given by Stokes Law (from Matthews, 1979, p.62) and the formula:

$$V_t = gd^2\rho_d \ / \ 18\eta$$

Where V_t = terminal velocity
d = droplet diameter
ρ_d = droplet density
g = gravitational acceleration
η = viscosity of air

However even given the doom and gloom over potential drift, most droplets reach the target or the ground within the orchard by falling under gravity.

There are two sides droplet size. Firstly smaller droplets are carried further in the airstream because gravity has less effect on them (see Stokes Law above). Small Low K droplets only travel because of the airstream. Small High K droplets rapidly decelerate to become the equivalent of Low K droplets and suffer the same fate. Once out of the airstream they are prone to drift, settling out on the crop target or somewhere off-target. Small droplets which miss the crop target may take a very long time to reach another target, exacerbated by the fact that they rapidly become smaller! The mathematics of droplet size, evaporation and airflow suggest that a large number of small droplets, containing very little active ingredient will unavoidably drift large distances, ie hundreds of metres. The only way to stop this is to capture the droplets within the orchard using windbreaks.

The most important factor is droplet size. This is compounded by the fact that small water droplets evaporate very rapidly, and get smaller! Thus while a 100 micron droplet takes 10.9 seconds to fall 3.0 metres and a 50 micron droplet takes 40.5 seconds, the 50 micron droplet will only survive 12.5 seconds at 20°C and 80% RH. At 30°C and 50%RH the 50 micron droplet only survives for 3.5 seconds in which it falls 0.032 m. That is in summer a 50 micron droplet (which you cannot see) blasted to 6.0 metres high in a macadamia canopy drops to about 5.968 m before it is a minute drop of pure pesticide!

The trials by Battaglia *et al.* (1997) showed that standard low profile airblast sprayers deposited the vast majority of droplets in the lower part of the canopy, mostly below 3.0 m (1997, Fig. 2).

However their measurements of recovery on to vertical 1 mm strings showed a much more even coverage up to 6 m (1997, Figs. 13 & 14). I believe this was due to collection of droplets by route (1), ie. directly from the sprayer, and ignored the great majority of droplets falling under gravity (2). Vertical string would not be a good catcher of falling droplets. Their trials showed interesting variation in droplet capture by string using different nozzles. These differences presumably relate to the droplet size and carriage within the airstream. Our trials suggest the overwhelming importance of routes (2) and (3) in recovery on macadamia leaves.

6.2 Exploratory models

6.2.1. Recovery depends on the proximity to the sprayer.

The simplest model would be that recovery at the different sampling sites was determined by proximity to the sprayer. FIGURE 6.1 gives a rating to each part of the canopy based on a maximum of 10 being 0-1 m from the fan axis. As shown below the recovery at MO would have an average proximity rating of 7, (6+7+8)/3. The averages for each site are given in TABLE 6.1.

FIGURE 6.1 Sampling site proximity rating based on proximity to fan axis.

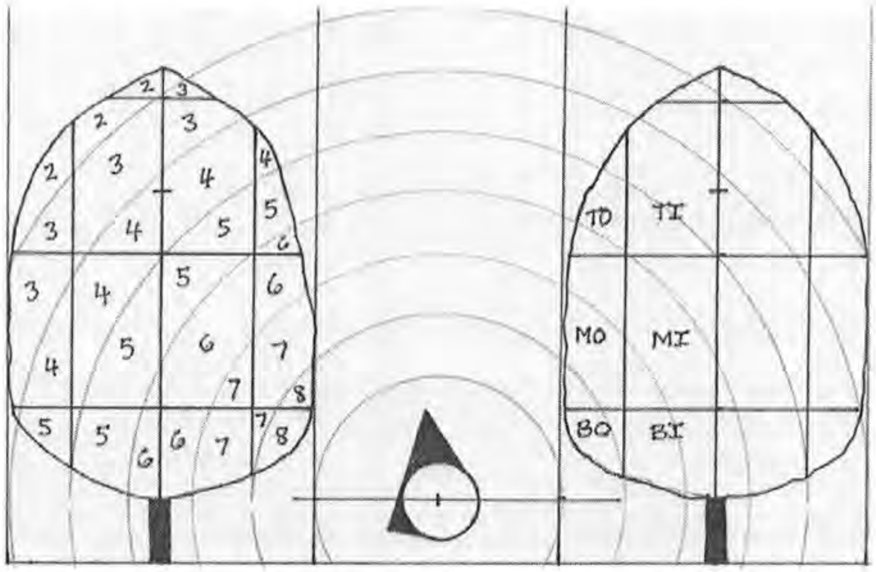
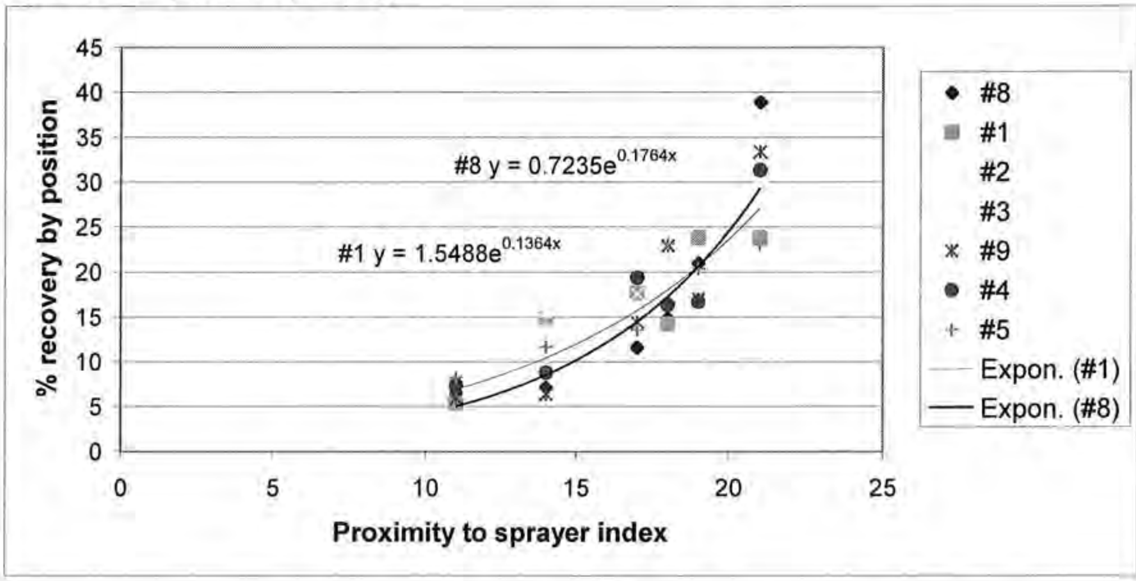


TABLE 6.1 Calculation of average and % proximity ratings.

Sampling site	Average proximity rating eg. (3+4+5)/3	Proximity to sprayer index. Expected % proximity rating eg. 4 / **36** x 100 =11%
TI	4	11
TO	5	14
MI	6	17
MO	7	19
BI	6.5	18
BO	7.5	21
Total	**36**	100

When the Actual % recovery is graphed against the Expected % proximity rating there would appear to be a good correlation, at least in T11 shown in FIGURE 4.45. Could it really be that simple!? If so this would suggest that one way to obtain more even recovery is to deliver droplets to the top of the tree from a CLOSER position. This could be achieved using a tower conveyor, such as the Barlow Tower, or by using separate fan heads on a tower, such as the Quantum Mist or Hydra. This model also suggests that recovery at BO and MO will be very similar, as will MI and BI. In general this is what was found in all the LP sprayer tests.

FIGURE 6.2 Correlation between actual recovery for all treatments in T11 and expected % proximity rating.



6.2.2 Recovery depends on the carrying capacity of the airstream.

Assuming that the airsream has a maximum efficiency for carrying spray it is possible to create a simple spreadsheet model to predict the recovery distribution for each application distribution.
A copy of the spreadsheet is given below:

FIGURE 6.3 Spreadsheet calculations for 30:50:20 spray distribution in Gowens 344 using the SS SF45 hf sprayer.

Canopy	**53333**	m3 canopy / hectare			
Row spacing	**9**	m			
Total air per side	**71611**	m3 / hr per side			
Speed	**2.0**	km / hr			
Spray volume	**3.0**	litres / 100 cubic m applied			
Standard	**0.050**	max. carrying capacity	L / cubic m air		
Dilute POR	6.0				
Row length	1111	m / hectare			
Litres/ hectare	1600	litres / hectare			
Litres / m row	1.44	litres / m row >>>>>>>>>>	%T	**30**	0.43
			%M	**50**	0.72
			%B	**20**	0.29
Air delivery	35.8	m3 / m row >>>>>>>>>>>>	%T	30	10.74
			%M	50	17.90
			%B	20	7.16
Air/spray density		litres / m3 air >>>>>>>>>>	T		0.040
			M		0.040
			B		0.040
Efficiency top	**0.3**				
Efficiency middle	**0.6**				
Efficiency bottom	**0.7**				
Capture middle	**0.25**				
Capture bottom	**0.75**		%T	**11%**	0.13
Estimated recovery			%M	**41%**	0.51
			%B	**48%**	0.59

The main assumptions of the model are:

- That the carriage of spray in the airstream reduces once the volume exceeds 0.05 L/m^3 air.
- That gravity increases the efficiency of droplet movement downwards, eg. 30% at the top, 60% in the middle and 70% at the bottom.
- That droplets not captured in the top of the canopy have an increasing chance of capture lower down, eg. 25% at middle and 75% at the bottom.

This model can predict the % recovery at T:M:B for various % distributions. TABLE X shows the actual and calculated recoveries for trial T14 reported in Section 5.4.

TABLE 6.2 Actual and Calculated % recoveries at Bottom, Middle and Top based on the application distribution.

Distribution	80:10:10		60:30:10		30:40:30		30:50:20	
	Act.	Calc.	Act.	Calc.	Act.	Calc.	Act.	Calc.
Bottom	60	58	55	50	49	54	42	48
Middle	25	28	28	35	30	35	38	41
Top	14	15	17	14	21	11	20	11

The calculated results illustrated in FIGURE X mirror the actual figures in showing that increasing the proportion applied to the top of the tree has little effect on recovery at the top. The main factors which determine this are the cumulative effects of gravity and capture efficiency as droplets fall through the canopy.

FIGURE 6.4 Actual and calculated recoveries at Bottom (B), Middle (M) and Top (T) based on distribution.

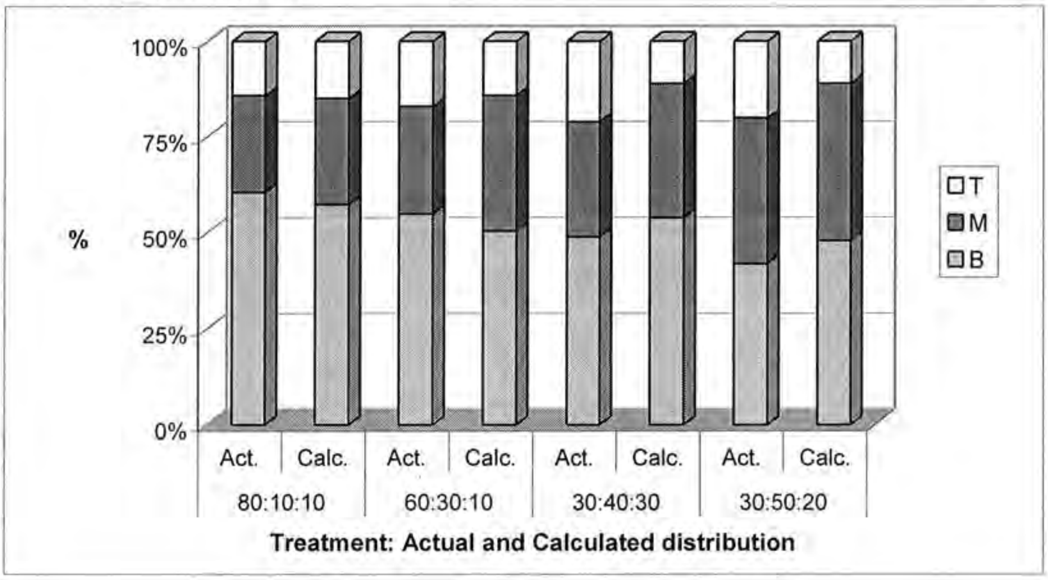
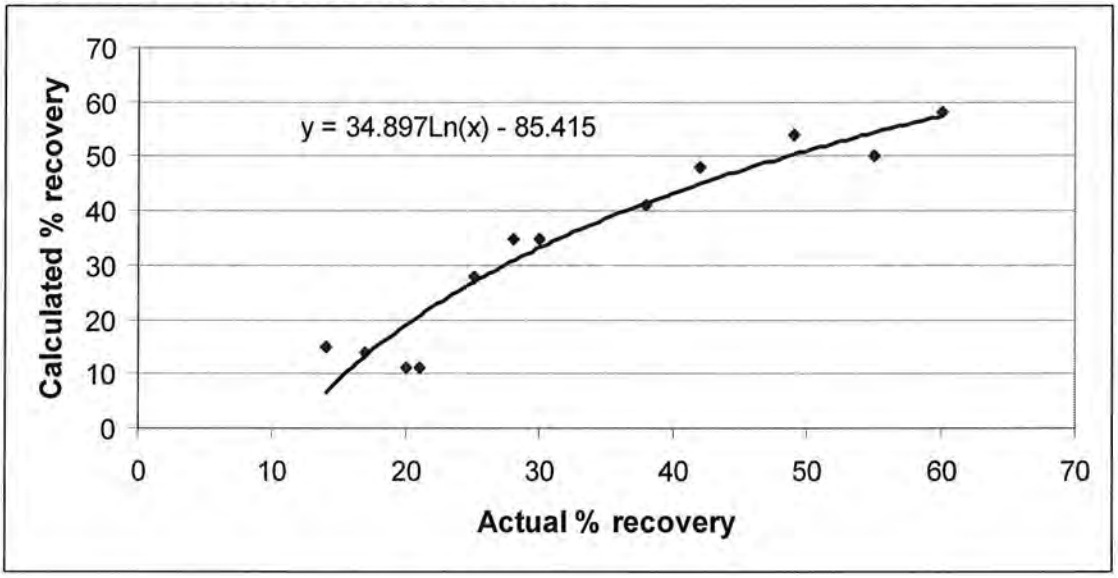


FIGURE Y shows the correlation between actual and calculated % distribution based on the above spreadsheet. The model is less accurate at the lower % application distributions to the top of the tree, where other factors must come into play.

FIGURE 6.5 The predictions of the model.



6.3 Summary

The trials carried out to assess the different technologies did not give the expected results because in devising our trial plan we assumed that the processes involved in airblast and airshear spraying were largely based on canopy air displacement, the model accepted in QDPI literature for 20 years. Our early results made us carry out further unplanned trials and tests to verify that our procedures were not giving false results.

We now believe that the canopy air displacement process is of relevance only at the bottom of the canopy and at very low tractor speeds. However in most instances this process is swamped by the effects of droplets falling from higher in the canopy. These may fall directly under gravity, through drift or as runoff. Given these assumptions it should be easy to achieve good coverage at the bottom of the canopy even when almost no spray is directed to the bottom. This appears to be the case as in T14 an 80:10:10 application distribution gave similar results to a 30:40:30 distribution.

While it seems to be easy to spray the bottom of the canopy at almost any volume or speed it is still difficult to spray the top. This appears to be because the airstream cannot carry droplets from hollow cone jets efficiently above 6 metres and because there is relatively little depth of canopy there to catch them anyway. A leaf at the bottom of the canopy has a far greater chance of catching droplets because it can capture droplets that were directed to the top, the middle and the bottom.

Solutions to increasing the coverage at the top are to either increase the kinetic energy of droplets directed to the top of the tree or to deliver them from a closer position using some type of tower structure or conveyor. A more difficult challenge may be to <u>decrease</u> the capture of droplets at the bottom. This argument explains why coverage from sprays applied by helicopter are so even throughout the canopy. Droplets are delivered above the canopy and slowly filtered out as they fall under gravity. There are more droplets at the top but they are captured ever more efficiently as they fall.

In assessing the operating constraints of the various sprayers and the risks to the environment drift is an important issue. Unfortunately it appears that, for most airblast and all airshear sprayers, drift is an essential component of the coverage process. You cannot get good coverage, at least in the upper parts of the canopy, without drift.

Hollow cone jets have been promoted in local extension literature for many years as the best nozzles for airblast spraying, on the basis of a more even droplet size than solid cone jets (eg. Hughes et al., 1997, p.15). However the QDPI data available in that same publication shows that for the same orifice size there is a smaller proportion of droplets in the "drift risk" category of 0-70 µm with the solid cone. For example at 15 bar the proportion in the 0-70 µm range falls from 19% for a hollow cone to 18, 14 and 12% for a 1.0 solid cone with 1.0, 1.2 and 1.5 swirl, respectively. Solid cones produce a much higher proportion of large droplets in the 250-1900 µm range than hollow cones and these have generally been considered too large to be effectively carried by an airstream. However with their own kinetic energy this may in fact be unimportant. The promotion of hollow cones and a narrower droplet spectrum may also be flawed, in that a range of droplet sizes may better reach the diversity of targets in a real canopy situation. This is supported by work by Ebert *et al.* (c.2000) at the Ohio Agricultural research & Development Centre, USA, who found that uniform coverage is not the best [pesticide] deposit structure if one is forced to limit application rates and that should result in more insects acquiring sub-lethal doses. This is the reverse of the last 20 years dogma.

In conclusion, in spraying tall canopies greater emphasis needs to be placed on droplet delivery than on spray volume, tractor speed or air volume.

7. TECHNOLOGY TRANSFER

Presentations have been made by project team members on the following occasions.

AMS Industry Field Day held at Eureka, NSW, on 24 August 2001
Presentations were made by Henry Drew and Graham Betts at the AMS Industry Field Day held at Eureka, NSW, on 24th August 2001 (attendance c.150). The sprayer calibration demo could not be held due to lack of time.

Macgroups 2001
Henry Drew attended the following MacGroups:
The MacGroup held at Bundaberg, Qld, on 28th August (attendance c.12).
The MacGroup held at Gympie, Qld, on 29th August (attendance c.30).
The MacGroup held at Glasshouse Mtns, Qld, on 30th August (attendance c.40).
The MacGroup at Atherton, Qld, on 11th October (attendance c.16).
The MacGroup at Nambucca, NSW, on 6th December (attendance c.25).

The AMS Conference held at Tweed Heads, NSW, on 26 October 2001
A presentation of trial results was made by Henry Drew at the AMS Conference with approximately 150 growers in attendance.

AMS R&D Pest Subcommittee on 19 February 2002.
An update was given by Henry Drew to the AMS R&D Pest Subcommittee in Brisbane.

AMS Pest Consultants Workshop on 13 August 2002
A presentation of trial results was made by Henry Drew to the industry consultants workshop in Brisbane on 13/8/02. Approximately 20 pest consultants were in attendance.

AMS Industry Field Day held at Wollongbar, NSW, on 30 August 2002
A presentation of trial results was made by Henry Drew at the industry field day at Wollongbar, NSW. Approximately 100 growers were in attendance. This was followed by a practical calibration demo carried out with the assistance of Graham Betts (Ask GB) and Robert Bianco (Rural Buying Machinery Centre P/L). Approximately 40 growers were in attendance.

M'ANIC 2002 Conference at Coffs Harbour, NSW, on 9-12 October 2002
A presentation on the importance of pesticide dose and IPM was made by Henry Drew at the industry conference in Coff's Harbour, NSW, on 11/10/02. This has been published in the conference proceedings.

AMS Canopy Management Field Day at Alstonville, NSW on 15 July 2003
A presentation of trial results relating to canopy management was made by Henry Drew at the field day at Alstonville, NSW. Approximately 50 growers were in attendance.

AMS Pest Consultants Workshop on 27 August 2003
A presentation of trial results was made by Henry Drew to the industry consultants workshop in Brisbane on 27/8/03. Approximately 25 pest consultants were in attendance.

Second International Macadamia Symposium at Tweed Heads, NSW, on 9-12 October 2002
A presentation on the critical factors in spraying macadamias IPM was made by Henry Drew at the international symposium at Tweed Heads, NSW, on 4/10/02. This has been published in the conference proceedings.

Publications

- Drew, H.J. (2002). Background to managing pesticide dose in macadamias. AMS Bulletin, Vol.29, No.4, 54-57.
- Drew, H.J., Betts, G.B. and Geitz, G. (2002). What is the appropriate Dilute spray volume in macadamias? AMS Bulletin, Vol.29, No.4, 58-62.
- Drew, H.J. (2002). The meaning of IPM or how can I still use pesticides? Paper presented at the M'ANIC 2002 Conference at Coffs Harbour, NSW, on 9th –12th October 2002. Australian Macadamia Society, Lismore, Australia. This has now been published in the conference proceedings.
- Drew, H.J. (2003). Critical issues in spray application in macadamias using ground-based air-assisted sprayers. Paper presented at the Second International Macadamia Symposium at Tweed Heads, NSW on 29th September – 4th October. Australian Macadamia Society, Lismore, Australia. This has now been published in the conference proceedings.

8. RECOMMENDATIONS

RECOMMENDATION 1
That 6.0 L/100m^3 be adopted as the industry Standard for Dilute spraying (1X) and as the benchmark for the conversion to Concentrate spraying in macadamias in the range of 2X to 5X.
This recommendation is based both on the above trial results, and on the need for a conservative figure which gives growers flexibility to use Concentrate sprays effectively but with little increase in risk.

RECOMMENDATION 2
That the above recommendation should be included in any revisions of the macadamia industry Code of Sound Orchard Practices (O'Hare *et al.*, 2000).

RECOMMENDATION 3
That growers investigate the use of solid cone jets, rather than hollow cone jets, to improve coverage at the top of the tree and reduce drift.

RECOMMENDATION 4
That the use of very small jets at very high pressures (over 20 bar) be discouraged due to the unneccessary risks of off-target drift.

RECOMMENDATION 5
That the AMS make spray equipment suppliers more aware of the need for nozzle extensions to ensure that droplets are not lost from narrow airstreams.

RECOMMENDATION 6
That the AMS liase with the manufacturers of straight through tower fans to further investigate their use in macadamias.

RECOMMENDATION 7
That the AMS investigate the feasibility of supplying small quantities of water sensitive papers for growers to use in calibration assessments.

RECOMMENDATION 8
That the AMS investigate the feasibility of setting up a confidential calibration database of growers sprayers. This could form the basis for an industry-managed accreditation system.

RECOMMENDATION 9
That the AMS fund a series of on-farm, hands-on workshops in 2004 to allow dissemination of the information generated by the MC00041 project to macadamia growers[1].

[1] The proposed project had been approved at the time of writing.

9. ACKNOWLEDGEMENTS

The Project Team consisted of:

Dr Henry Drew (Project Leader)
and Mrs Jenny Drew,
HJ & JM Drew Consultants,
283 Hunchy Rd, Hunchy, QLD 4555. Tel 07 5445 0032.

Mr Graham Betts,
Agricultural Spray Kare P/L trading as Ask GB,
Po Box 296, Drayton North, QLD 4350. Tel 07 4613 4220.

Mr Glenn Geitz,
Queensland Horticulture Institute, Gatton Research Station,
Locked Bag 7, Gatton, QLD 4343. Tel 07 5466 2222.

Mr Chris Fuller,
Macadamia pest consultant,
24 Gympie Rd, Kin Kin, QLD 4571. Tel 07 5485 4454

Thanks to the AMS (particularly Kim Jones, Andrew Pearce and Tim Salmon) and HAL (Jeff Petersen and Isabel Gray-Garraway) for funding and supporting this research.

Special thanks also to cooperating growers and spray equipment suppliers, whose contributions are detailed below. They included:

Mr. Max Gowen
Mr. Terry Morgan
Mr. Roger Arbuckle
Mr. David Carr
Mr. Bruce Henningsen
Mr. Bruce Ensing
Mr. Glenn Kenny
Mr. Erin Lynch
Mr. Cameron Lister

Orchards
T1-3,6-19. Thanks to Max Gowen and Sahara Farms, Glasshouse Mountains, for allowing use of their orchards, tractor, equipment and other resources free-of-charge.

T1-3. Thanks to Terry Morgan for allowing use of his orchard and water fill-up point free-of-charge.

T4-5. Thanks to Roger Arbuckle for allowing use of his orchard, tractor, equipment and other resources free-of-charge.

Sprayers
T1-2. Thanks to David Carr, Silvan Pumps and Sprayers, for making available a Silvan Supaflo airblast sprayer, SS SF45, free-of-charge. Thanks also for assistance with the trial.

T3. Thanks to Bruce Henningsen, Croplands Equipment, for making available a Croplands Cropliner airblast sprayer, DS SF35, and Quantum Mist sprayer, SS TF, free-of-charge. Thanks also for assistance with the trial.

T4. Thanks to David Carr, Silvan Pumps and Sprayers, for making available a Silvan Turbomiser airshear sprayer, DS CF T1, free-of-charge. Thanks also for assistance with the trial.

T5. Thanks to Roger Arbuckle, Boreen Point grower, for allowing use of his CDA Span sprayer, DS 8F T, free-of-charge.

T6. Thanks to Bruce Ensing, Nambour Tractors, for making available a Tecnoma Magistral airblast sprayer, DS DF45, free-of-charge. Thanks also for assistance with the trial.

T7-9, 11-18. Thanks to Cameron Lister, Glasshouse Mountains grower, for making available a Silvan Maxim airblast sprayer, SS SF40, free-of-charge.

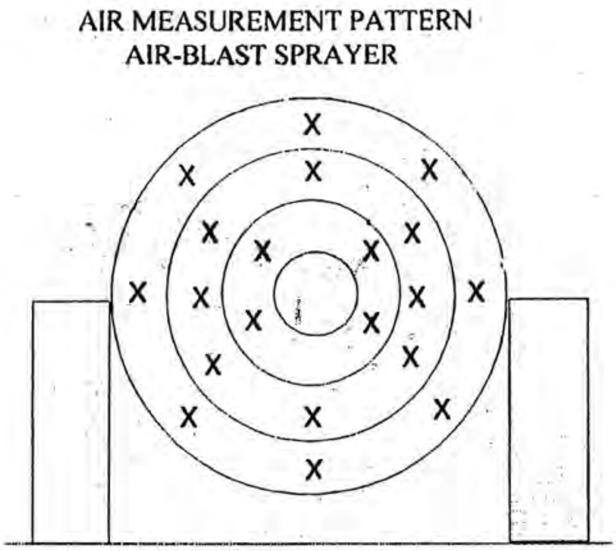
T10. Thanks to Glenn Kenny, Radak Systems, for making available a Silvan Supaflo with Radak Conveyor airblast sprayer, DS SF45 X, free-of-charge. Thanks also for assistance with the trial.

T11. Thanks to Max Gowen and Sahara Farms, Glasshouse Mountains growers, for making available a modified Silvan Electromiser (without electrostatics) airshear sprayer, DS CF T2, free-of-charge. Thanks to Erin Lynch, Erin Lynch Machinery, for assisting with the setup of this sprayer.

Analyses
Thank you to Dr Helen Wallace, University of the Sunshine Coast, Steven Coulter and Karina Pohio for help with statistical analyses.

10. APPENDICES

APPENDIX A. air inlet pattern looking from back of sprayer: Add all readings and divide by number of readings (20) to give average air velocity (m/sec).



Taken from Hughes, Dullahide and Battaglia (1997, p.24)

APPENDIX B.

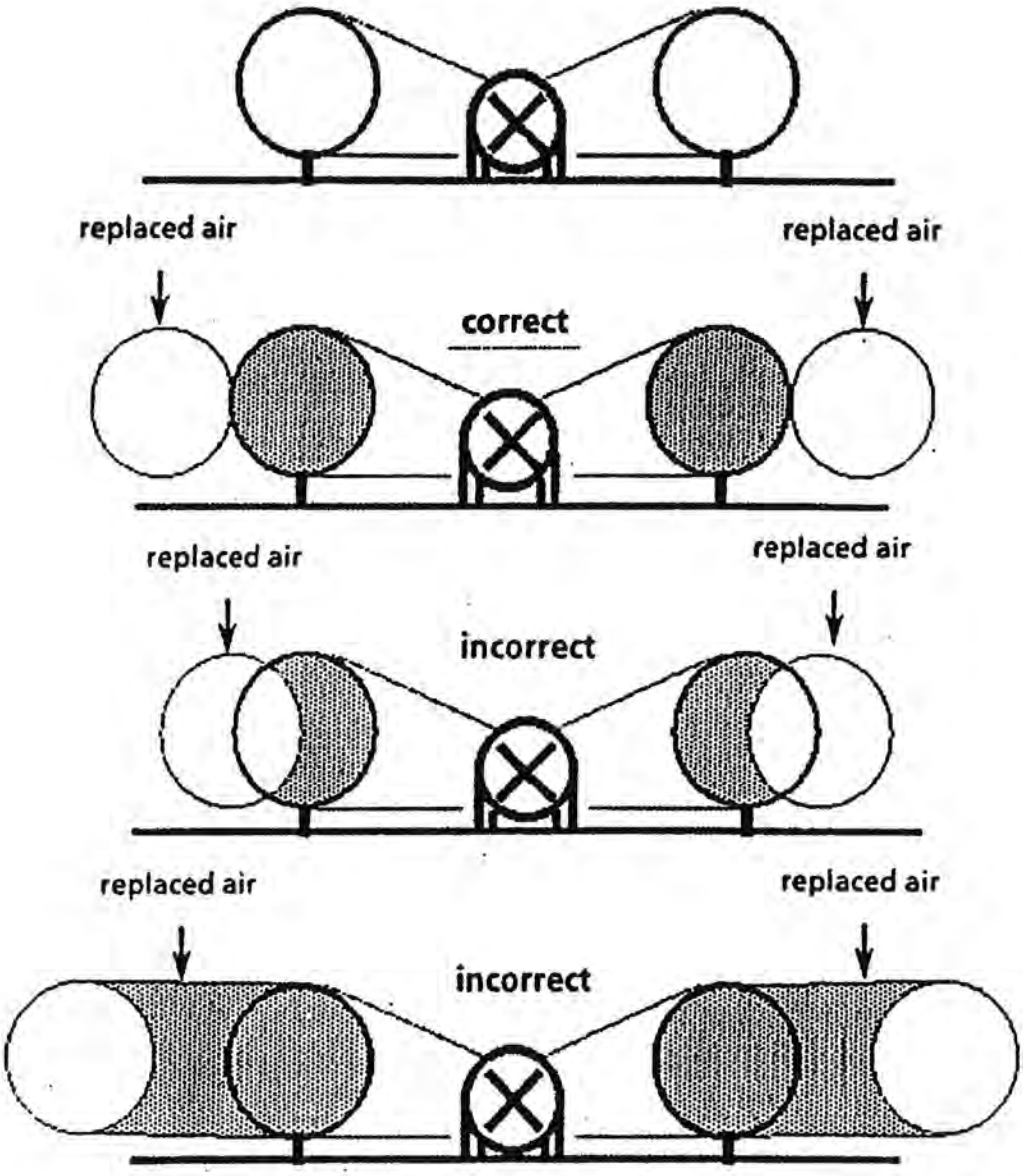
TABLE 5. NOZZLE SPECIFICATIONS AT VARIOUS OPERATING PRESSURES FOR *ALBUZ®* CERAMIC ATR NOZZLES

NOZZLE SIZE / COLOUR	PRESSURE		FLOW RATE•	DROPLET SIZE RANGE (µm)			
	BAR	PSI	L/min	0-70	70-250	250-1000	VMD*
				% of spray volume			
0.8 LILAC	5	70	0.37	20	79	1	94
1.0 BROWN	5	70	0.48	17	82	1	103
1.2 YELLOW	5	70	0.74	18	82	0	108
1.5 ORANGE	5	70	0.98	15	80	6	121
2.0 RED	5	70	1.39	13	79	8	131
2.3 GREEN	5	70	1.77	11	77	12	148
3.0 BLUE	5	70	2.45	8	69	22	174
0.8 LILAC	10	140	0.5	29	70	1	89
1.0 BROWN	10	140	0.66	29	70	1	87
1.2 YELLOW	10	140	1.02	18	81	1	108
1.5 ORANGE	10	140	1.34	21	76	3	110
2.0 RED	10	140	1.91	19	71	10	128
2.3 GREEN	10	140	2.44	19	72	9	132
3.0 BLUE	10	140	3.37	17	70	14	143
0.8 LILAC	15	210	0.61	38	61	1	81
1.0 BROWN	15	210	0.78	30	69	1	93
1.2 YELLOW	15	210	1.24	24	75	1	105
1.5 ORANGE	15	210	1.62	25	71	4	112
2.0 RED	15	210	2.3	27	69	4	112
2.3 GREEN	15	210	2.94	27	69	4	113
3.0 BLUE	15	210	4.06	26	68	6	116
0.8 LILAC	20	280	0.74	43	57	0	76
1.0 BROWN	20	280	0.96	41	59	0	81
1.2 YELLOW	20	280	1.43	31	69	0	94
1.5 ORANGE	20	280	1.96	31	68	2	104
2.0 RED	20	280	2.78	34	65	2	99
2.3 GREEN	20	280	3.54	36	63	1	96
3.0 BLUE	20	280	4.9	34	65	1	97

• Measured flow rate during testing. * VMD - volume median diameter

Taken from Hughes, Dullahide and Battaglia, (1997 p.17)

APPENDIX C. Principle of air displacement in orchard tree spraying



Taken from Hughes, Dullahide and Battaglia (1997, p.11)

APPENDIX D. Visual assessment of droplet densities

Visual assessment of droplet densities

Compare your spray samples with some known standard. The standard cards below and on the following page cover the range of acceptable droplet densities for coarse and medium LV spray. The droplet density in the target area should not be less than:

Numbers of droplets per cm^2*	Type of spray
20–30	Insecticides
20–30	Herbicides pre-emergence
30–40	Contact herbicides post-emergence
50–70	Fungicides

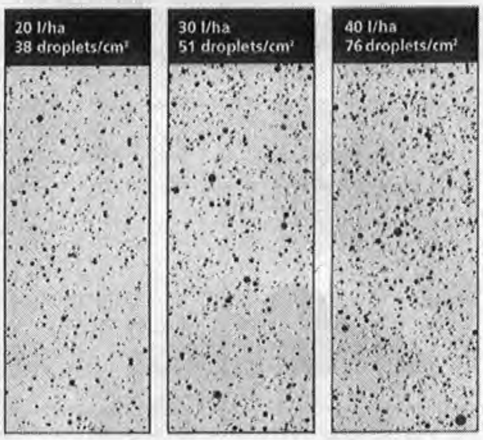
*1 cm^2 = 0.155 sq inch 1 sq inch = 6.452 cm^2

For routine checking of sprays you might also prepare your own standard cards by selecting spray cards with known droplet densities from previous spray operations.

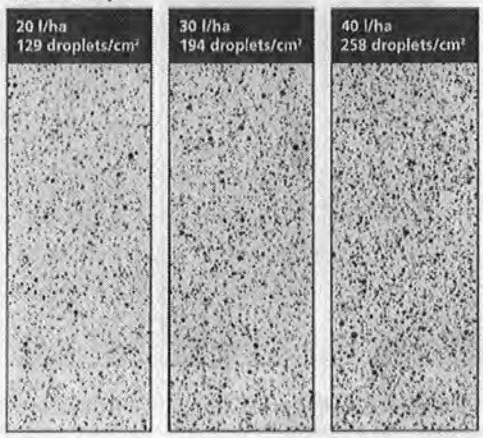
Standard cards with a known droplet density per cm^2

Computer-plotted standard cards displaying the expected number and sizes cards spraying at 3 different volume rates (20, 30, 40 l/ha) and using 3 different droplet spectra (VMD, 200, 300, 400 µm) assuming waters sprayed and the spread factor is two (see page 11).

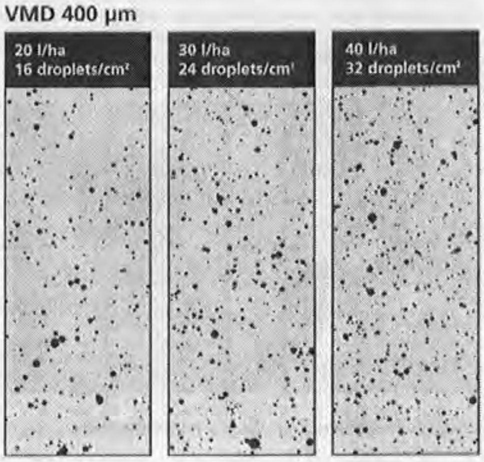
VMD 300 µm



VMD 200 µm



VMD 400 µm



Taken from Syngenta spraying booklet

APPENDIX E. FAN CHARACTERISTICS AND CALCULATIONS.

T1 & T2

Silvan SupaFlo, high fan, 45 deg., single-sided.
Max Gowen Block

Lutron AM-4203 Anemometer

outer	middle	inner		diammeter (mm)
13.2	15.6	14.3		950
8.6	18.5	17.1		**diammeter (m)**
1.2	15.2	12.5		**0.95**
13.3	13.1	15.3		minus diammeter (mm)
14.3	14.3			0
16.5	15.1			**minus diammeter (m)**
14.8	15.7			**0**
14.0	16.4			**effective fan area (m2)**
95.9	**123.9**	**59.2**		**0.71**

Total		**279**	
No.measurements		20	
Average air speed		**14.0**	m/s
Entrainment factor		2	
Air volume - Fan 1		**71611**	m3/hr
Air volume - Fan 2		0	
Total air volume		**71611**	m3/hr
Total air per side		**71611**	m3/hr
TCV/ha	MG	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		1	

T3

Croplands Cropliner - High speed, 35 deg., double-sided

Lutron AM-4203 Anemometer

Outer	Middle	Inner	
17.6	13.1	12.1	diammeter (mm)
15.2	12.4	11.0	920
12.5	11.1	10.4	**diammeter (m)**
10.9	9.0	11.3	**0.92**
13.1	11.1		minus diammeter (mm)
15.6	13.5		0
15.6	14.6		**minus diammeter (m)**
16.0	14.4		**0**
			effective fan area (m2)
116.5	**99.2**	**44.8**	**0.67**

Total	**260.5**	
No.measurements	20	
Average air speed	**13.0**	m/s
Entrainment factor	2	
Air volume - Fan 1	**62707**	m3/hr
Air volume - Qmist	0	
Total air volume	**62707**	m3/hr
Total air per side	**31353**	m3/hr
TCV/ha	53333	
TCV/km row	**48000**	m3
Tree spacing	4.5	m
Row spacing	9.0	m
Spraying sides	2	

T3

Croplands Quantum Mist alone - 1 head

Lutron AM-4203 Anemometer

inlet	outlet		diammeter (mm)
22.6	23.2		520
23.9	18.4		**diammeter (m)**
23.5	25.0		**0.52**
22.2	28.6		minus diammeter (mm)
	22.5		0
	26.2		**minus diammeter (m)**
			0
			effective fan area (m2)
92.2	**143.9**	**0**	**0.21**

Total	**236.1**	
No.measurements	10	
Average air speed	**23.6**	m/s
Entrainment factor	2	
Air volume - Fan 1	**36313**	m3/hr
Air volume - Fan 2	0	
Total air volume	**36313**	m3/hr
Total air per side	**36313**	m3/hr
TCV/ha	53333	
TCV/km row	**48000**	m3
Tree spacing	4.5	m
Row spacing	9.0	m
Spraying sides	1	

T3

Croplands Cropliner - High speed, 35 deg., double-sided + 2 Quantum Mist heads

Lutron AM-4203 Anemometer

Outer	Middle	Inner		diammeter (mm)
17.6	13.1	12.1		920
15.2	12.4	11.0		**diammeter (m)**
12.5	11.1	10.4		**0.92**
10.9	9.0	11.3		minus diammeter (mm)
13.1	11.1			0
15.6	13.5			**minus diammeter (m)**
15.6	14.6			**0**
16.0	14.4			**effective fan area (m2)**
116.5	**99.2**	**44.8**		**0.67**

Total	**260.5**	
No.measurements	20	
Average air speed	**13.0**	m/s
Entrainment factor	2	
Air volume - Fan 1	**62707**	m3/hr
Air volume - Qmist	72626	
Total air volume	**135333**	m3/hr
Total air per side	**67666**	m3/hr
TCV/ha	53333	
TCV/km row	**48000**	m3
Tree spacing	4.5	m
Row spacing	9.0	m
Spraying sides	2	

T4

Silvan Turbomiser with 3 heads at 600, 1600 and 2800 mm double-sided

Lutron AM-4203 Anemometer

Inlet outer	Inlet middle		diammeter (mm)
25.4	26.5		320
27.0	29.2		**diammeter (m)**
28.1	29.6		**0.32**
26.3			minus diammeter (mm)
20.8			0
29.4			**minus diammeter (m)**
28.6			**0**
27.5			**effective fan area (m2)**
213.1	**85.3**	**0**	**0.08**

Total	**298.4**	
No.measurements	11	
Average air speed	**27.1**	m/s
Entrainment factor	2	
Air volume - Fan 1	**15800**	m3/hr
Air volume - Fan 2	0	
Total air volume	**15800**	m3/hr
Total air per side	**7900**	m3/hr
TCV/ha	43750	
TCV/km row	**35000**	m3
Tree spacing	4.0	m
Row spacing	8.0	m
Spraying sides	2	

T5 @ 1500 rpm

Span CDA @1500 rpm with 4 heads at
1000, 2300, 3750 and 5350 mm, double-sided

Lutron AM-4203 Anemometer

Bottom Right	Bottom Left		diammeter (mm)
11.5	16.5		620
10.6	16.2		**diammeter (m)**
12.0	15.8		**0.62**
13.8	16.4		minus diammeter (mm)
14.0	16.5		150
14.5	17.0		**minus diammeter (m)**
			0.15
			effective fan area (m2)
76.4	**98.4**	**0**	**0.29**

Total	**174.8**			
No.measurements	12			
Average air speed	**14.6**	m/s		
Entrainment factor	2			
Number of fans	8			
Air volume - Fan 1	**239882**	m3/hr		
Air volume - Fan 2	0			
Total air volume	**239882**	m3/hr	>>>>	**29985**
Total air per side	**119941**	m3/hr		m3/hr per head
TCV/ha	43750			
TCV/km row	**35000**	m3		
Tree spacing	4.0	m		
Row spacing	8.0	m		
Spraying sides	2			

T5 @ 1800 rpm

Span CDA @1800 rpm with 4 heads at
1000, 2300, 3750 and 5350 mm, double-sided

Lutron AM-4203 Anemometer

Bottom Right	Bottom Left		diammeter (mm)
24.0	14.5		620
16.8	16.7		**diammeter (m)**
16.1	18.3		**0.62**
16.0	19.2		minus diammeter (mm)
15.7	18.2		150
16.4	15.3		**minus diammeter (m)**
			0.15
			effective fan area (m2)
105	**102.2**	**0**	**0.29**

Total	**207.2**			
No.measurements	12			
Average air speed	**17.3**	m/s		
Entrainment factor	2			
Number of fans	8			
Air volume - Fan 1	**284346**	m3/hr		
Air volume - Fan 2	0			
Total air volume	**284346**	m3/hr	>>>>	**35543**
Total air per side	**142173**	m3/hr		m3/hr per head
TCV/ha	43750			
TCV/km row	**35000**	m3		
Tree spacing	4.0	m		
Row spacing	8.0	m		
Spraying sides	2			

T6

Tecnoma Magistral ASD - Inner fan

Lutron AM-4203 Anemometer

outer	middle	inner	diammeter (mm)
8.6	14.4	11.6	920
12.5	15.1	13.5	**diammeter (m)**
11.9	12.6	8.2	**0.92**
9.3	8.4	12.0	minus diammeter (mm)
11.4	2.0		0
11.4	10.4		**minus diammeter (m)**
9.1	10.9		**0**
8.6	11.2		**Effective area (m2)**
82.8	**85**	**45.3**	**0.67**

Total	**213.1**
No.measurements	20
Average air speed (m/s)	**10.7**
Entrainment factor	2
Air volume - Fan Inner	**51297**
Air volume - Fan outer	40916
Total air volume (m3/hr)	**92213**
Total air per side	**46106**
TCV/ha	53333
TCV/km row	**48000**
Tree spacing (m)	4.5
Row spacing (m)	9.0
Spraying sides	2

T8

Listers Silvan - Maxim, high fan, 40 deg., single sided. Cv. 344

Kane-May KM4007 Airflow Meter *

outer	middle	inner	
19.2	17.2	11.9	diammeter (mm) 950
18.6	14.4	9.1	**diammeter (m)**
16.3	14.3	8.1	**0.95**
19.6	16.8	10.4	minus diammeter (mm)
15.7	15.2		0
16.5	11.6		**minus diammeter (m)**
13.1	12.6		**0**
16.2	12.8		**effective fan area (m2)**
135.2	**114.9**	**39.5**	**0.71**

Total		**289.6**	
No.measurements		20	
Average air speed		**14.5**	m/s
Entrainment factor		2	
Air volume - Fan 1		**74332**	m3/hr
Air volume - Fan 2		0	
Total air volume		**74332**	m3/hr
Total air per side		**74332**	m3/hr
TCV/ha	344	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		1	

* Lutron AM-4203 Anemometer damaged in vehicle accident and replaced with Kane-May KM4007 Airflow Meter

T9 LOW

Listers Silvan - Maxim, low fan, 40 deg., single sided. Cv. 344

Kane-May KM4007 Airflow Meter

outer	middle	inner		diammeter (mm)
13.1	15.2	10.7		950
14.9	14.2	11.7		**diammeter (m)**
14.7	12.9	13.3		**0.95**
12.0	15.2	9.3		minus diammeter (mm)
10.5	16.3			0
15.1	12.1			**minus diammeter (m)**
12.7	11.4			**0**
13.6	12.6			**effective fan area (m2)**
106.6	**109.9**	**45**		**0.71**

Total		**261.5**	
No.measurements		20	
Average air speed		**13.1**	m/s
Entrainment factor		2	
Air volume - Fan 1		**67119**	m3/hr
Air volume - Fan 2		0	
Total air volume		**67119**	m3/hr
Total air per side		**67119**	m3/hr
TCV/ha	344	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		1	

T9 HIGH

Listers Silvan - Maxim, high fan, 40 deg.,
single sided. Cv. 344

Kane-May KM4007 Airflow Meter

outer	middle	inner		diammeter (mm)
20.0	15.6	11.1		950
17.6	14.7	12.0		**diammeter (m)**
11.8	14.0	12.9		**0.95**
17.4	14.5	10.8		minus diammeter (mm)
9.2	15.2			0
15.0	16.2			**minus diammeter (m)**
13.8	15.5			**0**
14.6	12.4			**effective fan area (m2)**
119.4	**118.1**	**46.8**		**0.71**

Total		**284.3**	
No.measurements		20	
Average air speed		**14.2**	m/s
Entrainment factor		2	
Air volume - Fan 1		**72972**	m3/hr
Air volume - Fan 2		0	
Total air volume		**72972**	m3/hr
Total air per side		**72972**	m3/hr
TCV/ha	344	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		1	

T11 LOW

Silvan - Supa Flo, low fan, 45 deg., double-sided RADAK

Lutron AM-4203 Anemometer

outer	middle	inner	diammeter (mm)
14.4	14.3	13.6	1100
15.3	13.4	12.9	**diammeter (m)**
14.4	14.3	13.3	**1.1**
14.2	12.4	14.8	minus diammeter (mm)
14.3	13.1		0
16.1	13.5		**minus diammeter (m)**
17.5	15.7		**0**
16.3	16.1		**effective fan area (m2)**
122.5	**112.8**	**54.6**	**0.96**

Total		**289.9**	
No.measurements		20	
Average air speed		**14.5**	m/s
Entrainment factor		2	
Air volume - Fan 1		**99762**	m3/hr
Air volume - Fan 2		0	
Total air volume		**99762**	m3/hr
Total air per side		**49881**	m3/hr
TCV/ha	344	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		2	

T11 HIGH

Silvan - Supa Flo, high fan, 45 deg.,
double-sided RADAK

Lutron AM-4203 Anemometer

outer	**middle**	**inner**	**diammeter (mm)**
20.4	17.4	15.3	1100
17.6	15.6	14.6	**diammeter (m)**
16.4	15.5	15.3	**1.1**
15.7	15.1	15.3	minus diammeter (mm)
17.2	14.1		0
18.6	15.7		**minus diammeter (m)**
21.3	17.4		**0**
17.3	16.6		**effective fan area (m2)**
144.5	**127.4**	**60.5**	**0.96**

Total		**332.4**	
No.measurements		20	
Average air speed		**16.6**	m/s
Entrainment factor		2	
Air volume - Fan 1		**114387**	m3/hr
Air volume - Fan 2		0	
Total air volume		**114387**	m3/hr
Total air per side		**57193**	m3/hr
TCV/ha	344	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		2	

T12

Sahara Farms Airshear - LEFT & RIGHT

outer	middle	inner	diammeter (mm)
20.4	21.5	18.0	320
20.7	22.8	20.5	**diammeter (m)**
23.6	13.3	21.7	**0.32**
20.7	21.0	22.5	minus diammeter (mm)
13.1	22.1		60
18.0	18.8		**minus diammeter (m)**
15.3	19.6		**0.06**
10.2	5.3		**Effective area (m2)**
142	**144.4**	**82.7**	**0.08**

Total	**369.1**
No.measurements	20
Average air speed (m/s)	**18.5**
Entrainment factor	2
Air volume - LEFT	**10371**
Air volume - RIGHT	8304
Total air volume (m3/hr)	**18675**
Total air per side	**9338**
TCV/ha	53333
TCV/km row	**48000**
Tree spacing (m)	4.5
Row spacing (m)	9.0
Spraying sides	2

T13 @ 1800 rpm

Span CDA @1800 rpm with COWLINGS
at 1000, 2300, 3750 and 5350 mm, double-sided

Lutron AM-4203 Anemometer

Bottom Right	Bottom Left			diammeter (mm)
12.5	0.0			620
11.7	0.0			**diammeter (m)**
10.1	0.0			**0.62**
9.8	0.0			minus diammeter (mm)
10.7	0.0			150
11.4	0.0			**minus diammeter (m)**
11.7				**0.15**
10.9				**effective fan area (m2)**
88.8	**0**	**0**		**0.29**

Total	**88.8**		
No.measurements	8		
Average air speed	**11.1**	m/s	
Entrainment factor	2		
Number of fans	8		
Air volume - Fan 1	**182794**	m3/hr	
Air volume - Fan 2	0		
Total air volume	**182794**	m3/hr >>>>	**22849**
Total air per side	**91397**	m3/hr	m3/hr per head
TCV/ha	43750		
TCV/km row	**35000**	m3	
Tree spacing	4.0	m	
Row spacing	8.0	m	
Spraying sides	2		

T14

Listers Silvan - Maxim, high fan, 40 deg.,
single sided. Cv. 344

Kane-May KM4007 Airflow Meter

outer	middle	inner		diammeter (mm)
19.2	17.2	11.9		950
18.6	14.4	9.1		**diammeter (m)**
16.3	14.3	8.1		**0.95**
19.6	16.8	10.4		minus diammeter (mm)
15.7	15.2			0
16.5	11.6			**minus diammeter (m)**
13.1	12.6			**0**
16.2	12.8			**effective fan area (m2)**
135.2	**114.9**	**39.5**		**0.71**

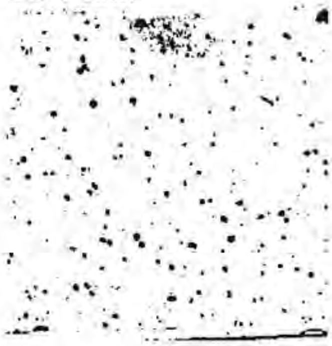
Total		**289.6**	
No.measurements		20	
Average air speed		**14.5**	m/s
Entrainment factor		2	
Air volume - Fan 1		**74332**	m3/hr
Air volume - Fan 2		0	
Total air volume		**74332**	m3/hr
Total air per side		**74332**	m3/hr
TCV/ha	344	53333	
TCV/km row		**48000**	m3
Tree spacing		4.5	m
Row spacing		9.0	m
Spraying sides		1	

APPENDIX F. Examples of WSP coverage for outers (BO) and ineers (BI)

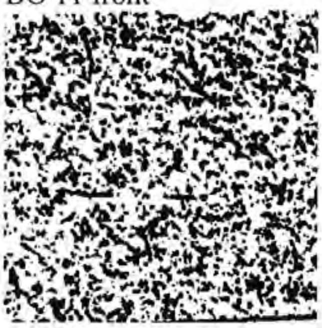
TREATMENT #1 OUTERS

BO 6 front

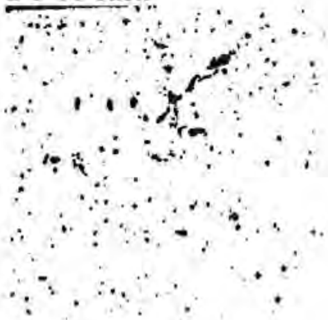
BO 6 back



BO 11 front

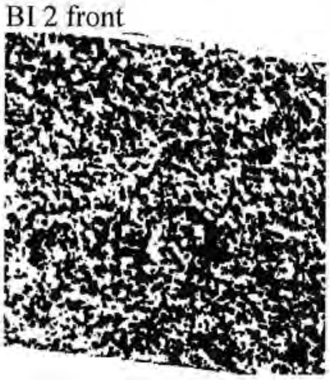


BO 11 back

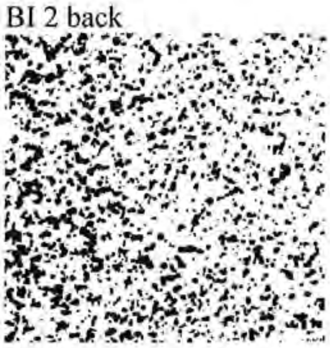


TREATMENT #1 INNERS

BI 2 front

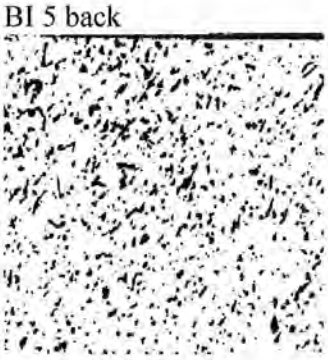


BI 2 back



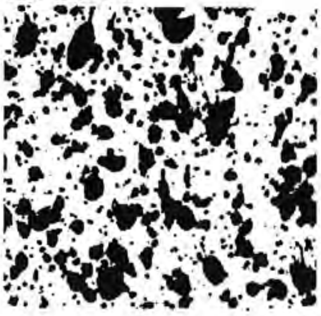
BI 5 front

BI 5 back



TREATMENT #2 OUTERS

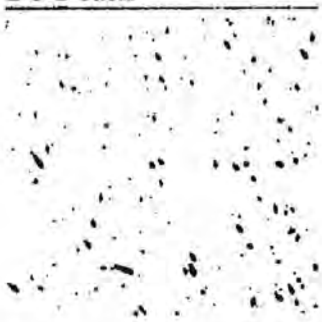
BO 8 front



BO 8 back

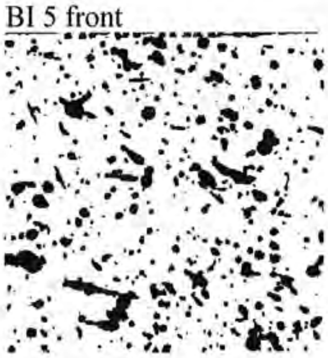
BO 2 front

BO 2 back



TREATMENT #2 INNERS

BI 5 front



BI 5 back

BI 2 front

BI 2 back

11. BIBLIOGRAPHY & OTHER USEFUL ARTICLES

- Albuz, (1989). Product leaflet.

- Banks, A. G. (1983). Spray application in macadamias. In R. A. Stephenson & E. C. Gallagher (Eds.), Proceedings of the First Australian Macadamia Research Workshop, Marcoola, Queensland, 12-16 September 1983. Lismore, New South Wales: Australian Macadamia Society.

- Banks, A., Broadley, R., Collinge, M., & Middleton, K. (1990). Pesticide application manual (2nd ed.). Brisbane, Australia: Queensland Department of Primary Industries.

- Battaglia, R., Woods, N., & Hughes, P. (1997). Workshop manual on efficient pesticide use in tree crops. Gatton, Australia: University of Queensland / HRDC / QDPI.

- Battaglia, R., Hughes, P., Cunningham, G., Duperouzel, D., Harper, S. and Dullahide, S. (c.1997). Pesticide reduction in pomefruit towards 2000: Pesticide application trials 1994-96. Horticultural Research & Development Corporation, Sydney, Australia.

- Battaglia, R. & Harden, J. (c.1997). Efficient and safe pesticide use as part of IPM strategies for macadamia production: Final report project no. MC615. Horticultural Research & Development Corporation, Sydney, Australia.

- Battaglia, R. (c.1998). Macadamia and avocado spray technology workshops: Final report project no. HG97011. Horticultural Research & Development Corporation, Sydney, Australia.

- Behncken, G. (Ed.). (1983). Pesticide application manual. QDPI Information Series QI83019. Brisbane, Australia: Queensland Department of Primary Industries.

- Bjugstad, N. (1994). Spraying application and deposit of pesticides in orchards. In Symposium on Engineering as a tool to reduce pesticide consumption and operator hazards in horticulture, Ulvik, Norway, 10-12 August 1993. Acta Horticulturae, 372, 93-102.

- Broadley, R., Haaksma, J., & O'Hare, P. (1993a). Evaluation of airblast sprayers for control of macadamia nutborer (Cryptophlebia ombrodelta) in mature macadamia trees (cultivar 344). Australian Macadamia Society News Bulletin, 20(1), 51-64.

- Broadley, R., Haaksma, J., & O'Hare, P. (1993b). Evaluation of airblast sprayers for control of macadamia nutborer (Cryptophlebia ombrodelta) in mature macadamia trees (cultivar 344) - 2. Further development of the Barlow spray tower. Australian Macadamia Society News Bulletin, 20 (3), 53-57.

- Bukovac, M. J., Reichard, D. L., & Whitmoyer, R. E. (1986). The spray application process: Central to the efficient use of growth regulators in tree fruits. Acta Horticulturae, 179, 35-45.

- Commonwealth of Australia. (1990). Report of the Senate Select Committee on Agricultural and Veterinary Chemicals in Australia, July 1990. Canberra: Australian Government Printing Service.

- Cross, J. (2002). Adjusting orchard sprayers to suit the crop. Good Fruit & Vegetables, August 2002, 52-53.

- Cunningham, G., Harper, S., Hughes, P. and Dullahide, S. (c.1995). Pesticide reduction in pomefruit towards 2000: Pesticide application trials 1994/95. Horticultural Research & Development Corporation, Sydney, Australia.

- Cunningham, G., Hughes, P., Dullahide, S. & Harden, J. (c.1996a). Efficient pesticide use in pomefruit: Workshop manual (1st Edition). Horticultural Research & Development Corporation, Sydney, Australia.

- Cunningham, G., Hughes, P. & Harden, J. (c.1996b). Efficient pesticide use in citrus: Workshop manual (2nd Edition). Horticultural Research & Development Corporation, Sydney, Australia.

- Drew, H.J. (2000). The management of pesticide application dose in Australian orchards: One glug or two? Doctoral thesis. University of Queensland, Brisbane, Australia.

- Ebert, T.A., Taylor, R.A.J., and Hall, F.R (c.2000). Importance of pesticide dose structure on dose response. Laboratory for Pest Control Application Technology, Ohio Agricultural Research & Development Centre, Ohio State University, Wooster, USA.

- Furness, G. O., Magarey, P. A., Miller, P. H., & Drew, H. J. (1998). Fruit tree and vine sprayer calibration based on canopy size and length of row: Unit canopy row method. Crop Protection, 17(8), 639-644.

- Geitz, G. (2002). Efficient pesticide application in vegetable crops: Workshop Manual. Queensland Department of Primary Industries, Brisbane, Australia.

- Hall, F. R. (1993). Application to plantation crops. In G. A. Matthews & E. C. Hislop (Eds.), Application technology for crop protection. Wallingford, UK: CAB International. pp. 187-213.

- Hughes, P., Dullahide, S. & Battaglia, R. (c.1997). Efficient pesticide use in pomefruit: Workshop manual (2nd Edition). Horticultural Research & Development Corporation, Sydney, Australia.

- Jones, A. (Ed) (2000). Improved labelling of pesticides to encourage optimum use in horticultural crops: Final report project no. AH99003. Horticultural Research & Development Corporation, Sydney, Australia.

- Koch, H., & Weisser, P. (1994). Variability of initial deposits of pesticides in orchards. [CD-ROM]. Zeitschrift fuer pflanzenkrankheiten und pflanzenschutz, 101(6), 634-640. Abstract from SilverPlatter 3.11: Biological Abstracts 1995/01-1995/06 Item: AN 199598171667.

- Lavers, A., Herrington, P. J., & Southcombe, E. S. E. (Eds.). (1991). Air-assisted spraying in crop protection. BCPC Monograph No. 46. Farnham: British Crop Protection Council.

- Manktelow, D. W. L., & Praat, J.-P. (1997). The tree-row-volume spraying system and its potential use in New Zealand. Proceedings 50th New Zealand Plant Protection Conference, (pp 119-124). Palmerston North: New Zealand Plant Protection Society.

- Matthews, G. A. (1979). Pesticide application methods. London, UK: Longman.

- O'Hare, P., Bell, D., Burton, D. & Salmon, T. (2000). Australian macadamia industry code of sound orchard practices, November 2000. Australian Macadamia Society, Lismore, Australia.

- QAC. (1986). Pesticide application and safety workshop for Gympie Fruitgrowers Association, 8 April 1986. Gatton, Australia: Queensland Agricultural College.

- Rowland, P. (1995). Recent changes in international crop protection practices: The growing trend to reduce pesticide use and pesticide risk. A DPIE Development Award Report. Canberra, Australia: Bureau of Resource Sciences.

- Rowland, P., & Bradford, D. (Eds.) (1998). Proceedings of the Australian National Pesticide Risk Reduction Workshop, Canberra, ACT, 16-18 April 1997. Canberra: Bureau of Resource Sciences, Agriculture, Fisheries and Forestry - Australia.

- Sutton, T. B., & Unrath, C. R. (1984). Evaluation of tree row volume concept with density adjustments in relation to spray deposits in apple orchards. Plant Disease, 68, 480-484.

- Sutton, T. B., & Unrath, C. R. (1988). A comparison of handgun and tree row volume pesticide applications. Plant Disease, 72, 509-512.