

Maximising Apple Orchard Productivity under Hail Netting

Final Report

PROJECT AP 96014

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HORTICULTURAL RESEARCH AND DEVELOPMENT CORPORATION

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MEDIA SUMMARY

The use of hail netting for the protection of a wide range of crops against hail damage has steadily increased in recent years. Hail netting of an orchard immediately makes it essential to produce the highest possible yields of premium quality fruit from the protected area of land, whilst minimising the costs of tree management and fruit production. Hail netting reduces fruit set, sunburn, windrub, fruit russet and bird damage, whilst also influencing yield, fruit size, fruit colour and maturity.

The management of trees under hail netting must aim to maintain good light distribution throughout the canopy. The key to achieving this is the control of tree vigour. Well managed trees under hail netting require less thinning and can produce larger and better coloured fruit than trees outside net, whereas overvigorous trees under net may produce smaller, poorly-coloured fruit as a result of excessive regrowth after pruning. Fruit can be grown in more exposed, well-illuminated positions under hail net than is possible without netting.

Pruning and crop load strategies to control excessive tree vigour under hail netting need to concentrate on 0 or light winter pruning, and light or chunk summer pruning. Heavy chunk winter pruning, whether done over one or two years, was accompanied by excessive regrowth which reduced yields and induced biennial bearing. Adequate space between the top of trees and the hail net is essential for optimum bee flight in netted orchards. To ensure good pollination, bee hives must be placed under the netting and introduced once flowering has commenced, usually about 3-5% bloom.

Economic analyses of hail netting showed that the market price received for apples was the major determinant of hail netting profitability. Using price data from Brisbane, Sydney and Melbourne markets, hail netting was found to be profitable for high value varieties such as Gala, Red Fuji and Pink Lady, irrespective of hailstorm incidence. This is becoming increasingly significant as hail netting becomes more widely used in regions where hailstorm incidence is low, for potential benefits such as ensuring fruit are free of sunburn and bird damage.

TECHNICAL SUMMARY

Hail netting for fruit protection gives hail-prone regions the ability to satisfy the fruit quality and fruit volume expectations of markets year after year. Covering an orchard with hail netting artificially creates a new environment, most obviously characterised by lower light levels. Trials in Qld, NSW and Victoria show that hail netting can cause:

- Reductions in light levels (PAR) of 12-27% (dependent on net type, mesh size and colour).
- Increased humidity of up to 10%.
- Up to 50% lower windspeed compared to outside netting.
- Slight reduction in daytime temperatures by 1-3°C on warm to hot days.
- Little effect on night-time temperatures, and does not offer frost protection.

The response of apple trees to hail netting is determined by tree vigour, pruning and crop load. Netting most noticeably affects tree growth, yield, fruit size and colour on vigorous trees that would have shading problems regardless of the presence of netting. Reduced fruit size and increased shoot growth occurred on vigorous trees under net at Stanthorpe, Orange and Drouin. Conversely, fruit size was increased on trees where vigour was under control. Improved fruit skin finish and reductions in sunburn, windrub and bird damage are obvious benefits of hail netting.

Fruit set was always lower on trees under netting. This permits potential cost savings through reducing the annual level of fruitlet thinning required, provided tree vigour is controlled and fruit size is maintained. Fruit size on vigorous trees under hail netting is reduced if inappropriate pruning strategies are used which encourage excessive shoot growth. The interaction between crop load, pruning, tree vigour, yield, biennial bearing and fruit quality (size, colour) was studied in detail. Pruning treatments included various combinations of chunk (heavy) dormant pruning, standard (lighter) dormant pruning, 0 pruning, chunk summer pruning and standard (lighter) summer pruning, in combination with light, medium and heavy crop loads.

Heavy chunk winter pruning increased fruit size over other pruning treatments in the year after treatment, however this was due to a reduction in crop load. Whether done over one or two seasons, heavy chunk winter pruning cannot be recommended as it was always accompanied by excessive regrowth which dramatically reduced yields in subsequent years and induced biennial bearing. Nil pruning in the winter before an 'off' season, followed the next season by light dormant pruning and/or summer pruning, effectively minimised shoot growth. High crop loads reduced regrowth, but also reduced average fruit size.

A pruning x crop load strategy for vigorous trees under hail netting should aim for a balance between tree vigour, crop load, fruit size and biennial bearing. On mature 15 year old Hi Early Red Delicious trees in Queensland and NSW this was achieved with a crop load of 400-500 fruit/tree (3.0 - 3.5 apples/cm² TCSA) and a pruning strategy of 0 or light winter pruning, followed by light or chunk summer pruning. Heavy winter chunk pruning should be avoided on overvigorous trees.

Measurements of bee activity under hail netting showed that adequate space between the top of the trees and the hail net is essential for optimum bee flight. Where there is little or no gap between the tree top and the net, bees are unable to fly freely and an uneven distribution of bees may occur in the block. Bees must be introduced under hail netting once flowering has commenced. Introduction of hives before this will only encourage bees to seek alternative nectar and pollen sources outside the netted area. Bees naturally tend to work along tree rows, however the more protected environment under netting can encourage increased bee foraging across alleyways and between adjacent tree rows.

A cost-benefit analysis, with a discount rate of 8%, was used to calculate the expected profitability of hail netting in Qld, NSW and Vic. Using price data from Brisbane, Sydney and Melbourne markets, hail netting was profitable for high value varieties such as Gala, Red Fuji and Pink Lady, irrespective of hailstorm incidence. The sensitivity of profitability to changes in cost, yield, packout and price of hail netting was also considered.

Future research and development needs to include:

- Chemical thinning – evaluate the efficacy of spray thinning under net and determine appropriate recommendations under hail netting.
- Tree physiological responses to hail net (photosynthesis, transpiration, source/sink relationships and dry matter partitioning) for tree management to fully exploit the netted environment.
- Crop load x irrigation studies with a view to reducing water use and maximising water use efficiency.

INTRODUCTION

The high incidence of hailstorms in many apple producing districts of Australia has meant that increasing numbers of orchardists are using hail net for the protection of fruit. On the Granite Belt it is estimated that 2000 hectares of orchard area are now covered with hail netting. To offset the high establishment costs, orchard productivity under hail netting must be maximised through both the production of high yields of premium quality fruit, and the minimisation of production costs. Nevertheless, the use of hail netting for fruit protection offers the most effective and economic means of ensuring the consistent supply of apples from hail-prone production regions.

The semi-protected environment beneath hail netting is most obviously characterised by lower light levels. Trials in apple orchards in Queensland, New South Wales and Victoria (Middleton and McWaters 1996) have shown that hail netting can cause:

- Reductions in light levels (PAR) of 12-27%.
- Increased humidity by up to 10%.
- Up to 50% lower windspeed compared to outside netting.
- Slight reduction of daytime temperatures by 1-3°C on hot days.
- No effect on night time temperatures, and does not offer frost protection.

Light interception and distribution are critical determinants of orchard productivity, and internal tree shading can reduce yield, fruit size, colour and TSS (Jackson and Palmer 1977; Doud and Ferree 1980). Such shading effects on tree performance can also occur beneath hail netting under Australian conditions (Middleton and McWaters 1996).

Few studies have been published on the influence of hail netting on tree productivity and orchard microclimate, and no work has been done on the management (tree density, pruning, thinning, irrigation) of trees for high productivity beneath hail net. Giulivo (1979) undertook measurements within orchards in northern Italy, but this data is inappropriate for Australian orchards, which experience higher light intensities and solar angles of incidence by virtue of their closer proximity to the equator as compared with northern Italy. Scott (1989) and Campbell (1991) have done some limited *ad hoc* climatic measures under hail net in Australia. In all cases, the environment within apple tree canopies, the effects on tree productivity, growth and water use, and appropriate tree management beneath hail net were not studied and are unknown.

Middleton and McWaters (1996) showed that hail net can offer substantial advantages for tree management and orchard productivity, but that pruning, irrigation and thinning strategies appropriate to trees under netting need investigation.

There is a reluctance by many orchardists to incur the expense of hail net installation until convinced that detrimental effects on orchard productivity do not occur. This project aims to show that the benefits of hail net are not just confined to protection from hail, but that significant productivity gains and production cost savings are possible with full exploitation of the hail net environment and the tree response to this. Such additional benefits should include reduced tree water use, reduced fruit sunburn, the ability to spray trees under windy conditions that would otherwise prevent spraying of unprotected trees, and the use of shading to encourage self regulating trees that respond well to chemical thinning and require minimal hand thinning. It is only with accelerated adoption of hail net by orchardists in hail prone districts that consistency of supply of quality fruit can be guaranteed to both domestic and export markets.

The climatic changes measured by Middleton and McWaters (1996) under hail netting also affect tree growth, fruit set, yield, fruit quality and bee movement. Large shading effects on orchard productivity under netting are due to excessive tree vigour (Middleton and McWaters 1996) and changes in the pruning, irrigation and thinning of trees under net are needed to maximise productivity. Hail netting

is a large investment, and it is essential that the shading effects of net are used to advantage to encourage self-regulating trees that produce high quality fruit at minimal cost. Growers with netted orchards need to maintain high yields and fruit quality to recoup their financial outlay.

This project consists of several distinct components:

- Evaluate the growth, yield and fruit quality responses of apple trees to the shaded environment beneath hail netting.
- Tree management trials (pruning x crop load) to control excessive tree vigour and maximise orchard productivity under netting.
- Measurement of bee activity under hail netting and the implications for the pollination of trees under net.
- Economic analyses of hail netting, including:
 - 'Risk' analysis to determine the incidence and severity of hailstorms necessary before it is economic to erect net for hail protection.
 - Cost/benefit analyses to also factor in the secondary benefits of hail netting, such as improved spray efficacy, lower water use, increased packout, reduced sunburn, hand thinning etc.
 - Costs and returns to determine what yields/packout are required before it is economically feasible to consider netting an orchard block.

MATERIALS AND METHODS

Trial sites

Fieldwork was undertaken within blocks of trees on commercial apple orchards in Queensland (Stanthorpe, latitude 28°37'S), New South Wales (Orange, latitude 33°19'S) and Victoria (Drouin, latitude 38°08'S). The trial sites included a range of hail net types, apple varieties and tree vigours, as summarised in Table 1.

Bee activity trials

Bee activity and the pollination of trees under hail netting is of critical interest to orchardists, particularly with the 'fixed-net' structures erected for hail protection in Queensland. A series of trials were conducted between 1996 and 1999 at sites 2, 4 and 5 (Table 1) to observe bee foraging behaviour under hail netting, and to determine the implications of these observations in the pollination of trees protected by hail net.

Bee foraging behaviour was observed by counting the number of bees actively working two adjacent trees over a 30 second period. The pairs of trees were sited at different distances and directions from hives positioned in the orchard. Bee counts on different pairs of trees were made simultaneously by up to four observers. The bees were counted at half hour intervals between 9am and 11:30am over several days during the blossoming period (early October on the Granite Belt). The 30 second counts were made on trees in standardised order, then repeated thereafter in that same order.

At full bloom, the total number of flower clusters on each tree was counted, and the trunk girth 15 cm above the graft union was measured. Fruitlets were counted six to seven weeks after full bloom, and fruit set calculated as both fruit number per 100 flower clusters, and fruit number per cm² TCSA (trunk cross-sectional area).

Apple tree response to hail netting

Trial sites

Trials to measure the effect of hail netting on apple tree growth, yield and fruit quality were initiated by Middleton and McWaters (1996) and continued in the current project. Sites 2, 3 and 6 (Table 1) were the major experimental sites used in this work.

To accurately measure apple tree response to hail netting is difficult, and requires blocks of identical trees (same date of planting, variety, rootstock, planting density, soil, tree management) planted adjacently, where hail netting has been erected over part of the block and the remainder of the block left uncovered. It was difficult to secure appropriate sites as growers erecting hail net tend to cover an entire block of trees, rather than leave some trees uncovered for comparative purposes.

Nevertheless, excellent trial sites (sites 2, 3 and 6) meeting these criteria were identified in Queensland, NSW and Victoria. Minimum block size was 0.5 hectare, but was usually much larger than this. Such a large 'plot' size ensured that the tree growth and productivity under hail netting measured in this project was typical of what occurs in the netting of commercial orchards.

Site 6 was located at the Queensland Department of Primary Industries Applethorpe Research Station, where we were in a short-term unique position to erect hail netting over 18 rows of trees in an apple high density planting systems trial, whilst leaving the adjacent 18 duplicate rows uncovered.

Table 1. The trial sites used for apple tree management experiments under hail netting (tree growth and productivity, bee activity, pruning and crop load).

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Location	Stanthorpe, Qld	Orange, NSW	Drouin, Vic	Stanthorpe, Qld	Stanthorpe, Qld	Stanthorpe, Qld
Variety	Red Delicious, (Hi Early)	Red Delicious (Hi Early)	Granny Smith	Royal Gala, Red Fuji,	Hi Early, Summerdel	Red Fuji (NF2), Hi Early, Royal Gala
Rootstock	Northern Spy	Northern Spy	Northern Spy	MM106, M7, M26	MM106	M26
Planted	1980	1983	1978	1990-1992	1990-1995	1993
1999 Girth (cm)	40.7	42.5	53.5	16.0 – 21.0	21.0	16.3
Tree Spacing	5.0 x 3.0 m	5.0 x 2.8 m	5.0 x 3.0 m	3.5 x 1.25 m	5.0 x 2.0 m	3.6 x various
Planting Density	666 trees ha ⁻¹	710 trees ha ⁻¹	666 trees ha ⁻¹	2280 trees ha ⁻¹	1000 trees ha ⁻¹	1400-3000 trees ha ⁻¹
Tree Training	Central leader	Central leader	Vase	Vertical Axis	Central Leader	Vertical Axis
Hail Net:						
-Type	Flat	Flat	Flat	Pitch	Pitch	Flat
-Colour	Black	Black	Black	White	White	Black, White

Tree growth and productivity

Detailed tree growth, blossoming, fruit set, yield and fruit quality measurements were made on a minimum of nine covered and nine uncovered trees at the Drouin site (site 3). Up to 75 covered and 75 uncovered trees were assessed in detail at the Orange site (site 2), and a similar number of trees under and outside hail netting were also assessed at the Queensland site (site 6).

Annual shoot growth was measured at sites 2 and 3 after the cessation of shoot growth, by counting and recording the lengths of all current season extension shoots >15 cm. For practicality, these measurements were restricted to 16 trees under hail net and 16 trees outside net at site 2 (Orange).

Butt circumference of all trees was measured annually in winter, 15 cm above the graft union, and measurements converted to cm² trunk cross-sectional area (TCSA).

Flower clusters were counted in October of each year and annual fruit set counts made in late November to early December, after natural fruitlet drop was completed. The fruit set of each tree was calculated as fruit set per 100 flower clusters, and fruit set per cm² TCSA.

At harvest, fruit from all trees were counted and weighed separately at one metre height intervals. Individual fruit circumferences were measured on all apples from 6 to 12 trees under and 6 to 12 trees outside net (depending on site), as a measure of the fruit size distribution. Individual fruit weights and circumferences were also taken from all apples from one tree under net and one tree outside the net, to correlate fruit weight with fruit circumference. Where practicable, apples from the Queensland trial sites were graded with a computerised electronic weight size grader (PSF Equipment) located at Applethorpe Research Station.

Fruit firmness and total soluble solids (TSS) were measured on a 100 fruit sample from ten trees under net and ten trees outside the net. These fruit were harvested from standardised locations within the apple tree canopy to account for any positional effects on fruit firmness and sugar content (Middleton and McWaters 1996).

An Atago hand refractometer was used to measure TSS (°Brix) and an Effegi hand penetrometer (Model FT 327) to pressure test fruit. Both instruments were used as per manufacturers guidelines and following normal procedures of fruit preparation.

Russet, windrub and sunburn were visually assessed on all fruit, using a scale of 1 (nil) to 5 (severe). The colour of red apple varieties was also assessed visually on a scale of 1 to 5, as illustrated in Appendix I for Hi Early. As with yields and other fruit quality parameters, data on the skin finish and appearance of apples was separately recorded for fruit from each one metre height interval.

The sample sizes used for fruit colour, russet and sunburn determinations varied, and are indicated in the appropriate Results tables.

Tree management under hail netting

Two major experiments to determine the appropriate management of trees under hail netting have concentrated on the effect of pruning and crop load on shoot growth, yield, fruit size, fruit quality and biennial bearing. Pruning and crop load experiments have been conducted at each of sites 1 and 2 (Table 1), and are broadly described below. Supplementary work has also been done at Drouin, Victoria (site 3).

Site 1 : Stanthorpe, Queensland.

Variety – Hi Early Red Delicious

1997/98

1998/99

- *Pruning experiment:*

- WINTER Chunk prune (heavy)	- WINTER standard (light/med)
- SUMMER Chunk prune (heavy)	- WINTER standard (light/med)
- 0 prune (control)	- WINTER standard (light/med)
- WINTER Standard prune (light/med)	- WINTER standard (light/med)
- WINTER Standard prune (light/med)	- WINTER standard (light/med)
+ SUMMER Standard prune	

- *Crop Load experiment:*

Heavy	>5.0 fruit/cm ² TCSA
Moderate	4.0 fruit/cm ² TCSA
Light	<3.0 fruit/cm ² TCSA

All trees at this site were covered by black hail net. The pruning experiment was a randomised block design using nine single-tree plots for each of the five pruning treatments, and trunk girth as a covariate. The crop load experiment was a factorial design incorporating all 15 pruning x crop load combinations. Data were analysed by analysis of variance (ANOVA).

Site 2 : Orange, NSW.

Variety – Hi Early Red Delicious

- *Pruning experiments:*

Several pruning experiments have been conducted over the past five years, and have included the following six pruning treatments :

- 0 prune (control)
- WINTER Standard : a few large cuts and several smaller, detailed cuts
- WINTER Chunk : ONLY large cuts were made, and included removal of structural wood
- SUMMER Chunk : ONLY large cuts were made, and included removal of structural wood
- SUMMER Standard : concentrated on removal of current season shoot growth
- WINTER Chunk + SUMMER Standard : pruning in both winter & summer, according to these two treatments

Different combinations of the above six pruning treatments have been used over successive years. For example, the WINTER Chunk (WIN Ch) treatment was applied to some trees for two successive years, followed by either a 0 prune or a WINTER Standard (WIN St) pruning treatment in the third season. To other trees WIN Ch pruning was done in only one year, followed by 0 winter pruning and

SUMMER Standard (SUM St) in the second season and WIN Ch pruning in the third year. Other trees were 0 pruned for two seasons, followed in the third season by either WIN Ch pruning or SUM Ch pruning. As a result of this strategy there were over 18 different pruning treatment combinations tested.

- *Crop load experiments:*

Heavy	>5.0 fruit/cm ²	TCSA
Moderate	4.0 fruit/cm ²	TCSA
Light	<3.0 fruit/cm ²	TCSA

The trials were designed as factorial experiments incorporating several crop load x pruning treatments. The pruning and crop load treatments were assigned to trees using trunk girth as covariate. A total of 156 experimental trees were used at this trial site. 78 trees were under black hail netting and were immediately adjacent to another 78 trees not covered by hail net. This permitted a direct comparison of tree response to pruning and crop load, with and without the presence of hail netting. Data was analysed by ANOVA.

Data collection

Trunk girth of all trees was measured 15 cm above the graft union in winter of each year, and converted to cm² TCSA (trunk cross-sectional area). Flower cluster counts were made on all trees in October of each year, and fruit set counts in late November to early December after the main period of apple fruitlet drop was completed. Hand thinning treatments were then immediately applied on the basis of calculated crop load/cm² TCSA. This broadly corresponded to crop loads of <3.0 (light), 4.0 (moderate) and >5.0 (heavy) fruit/cm² TCSA.

At harvest, all fruit from the experimental trees were counted and weighed. On lighter crop trees the diameters of all fruit were measured, whereas on heavier crop trees the fruit size distribution was determined by measuring the diameters of a 200 fruit sample taken by harvesting all the fruit from the top of the tree to ground level in a one metre wide strip on the eastern side of the tree. Average fruit weight was calculated by dividing the total yield by the fruit count, and fruit colour assessed visually on a scale of 1 to 5 (Appendix I). All fruit were colour assessed individually on the lighter crop trees, whereas the same 200 fruit sample previously described was used to assess fruit colour on the heavier crop trees.

In all experiments, winter prunings and summer prunings were weighed to give a measure of the tree canopy removed by each pruning treatment. The total leaf area removed in summer pruning was calculated from leaf counts and average individual leaf area (cm²). Separate counts of spur leaves and shoot leaves were made. Individual leaf areas were measured non-destructively in the field with a grid as described by Freeman and Bolas (1956), using a random sample of 100 spurs and ten extension shoots per tree. This gave a sample size of 200-250 leaves of each leaf type. The lengths of all annual shoot growth >15 cm were measured annually during the dormant season, when the lack of foliage made this large task easier. This gave an accurate measure of tree growth and invigoration following pruning treatments over all years of the pruning experiments.

The WIN Ch pruning treatment aimed to rapidly create a new tree framework with a well-defined central leader through the use of a few very large pruning cuts to remove structural wood and improve tree structure. The SUM Ch pruning treatment was identical to this, except done in summer after the cessation of annual shoot growth.

The WIN St pruning treatment did not attempt to alter the existing tree structure and framework, and consisted of many small secateur cuts (120 – 150), few large cuts and the maintenance of the existing tree structure. SUM St pruning again removed no structural wood, but concentrated on the removal of vigorous 1 yo shoots shading internal regions of the canopy.

RESULTS

Bee activity trials

At all sites, with the exception of Site 3 (Drouin, Vic), there were no bees present in the netted orchards prior to the introduction of bee hives. Bee activity was very dependent on weather conditions. On warm sunny days bees were far more active than on cooler windy days. Bee activity was nil or minimal on wet or drizzly days and detailed bee counts were not made on such days.

As observed by Middleton and McWaters (1996), general bee movement declined towards the middle of the day. Bees working the trees at this time tended to be pollen gatherers rather than nectar collectors, and were concentrated in the tops of the trees rather than lower down. A lot of guard bees were also evident at the entrances to hives, possibly due to low levels of nectar.

Bee counts made at Site 4 in October 1997 (Figure 1) are typical of the data collected from all sites. The bee numbers in Figure 1 are an average of 15 sets of counts (each of 30 seconds duration) made over three warm, sunny days just prior to full bloom. Five sets of counts were made between 9am and 11:30am on each of the three days.

Bee numbers declined with increasing distance from the hives. As observed previously by Middleton and McWaters (1996), bees actively worked in the more sheltered environment under net both along the rows and across alleyways between adjacent rows, provided their flight paths were not blocked by trees growing close to the height of the hail netting.

Fruit set also declined with increasing distance from the hives (Figure 2), emphasising the important role bees play in the pollination of apple trees under hail netting. The lowest fruit set of 40 fruit per 100 flower clusters measured at this site was just acceptable, and a tendency for reduced fruit set at greater distances from the hives was very evident. This trend will occur regardless of the presence of netting.

The fruit set counts in this particular orchard show that the hive density used and the introduction of the hives into the netted orchard at approximately 20% bloom ensured adequate pollination throughout the block. The white net used at this site was erected on a low-set gable structure, and significant numbers of disorientated bees were observed within the pitch of the hail net above the trees. Providing a sufficient gap between the top of the trees and the height of the hail net was found to be critical to minimising bee entrapment in netting and ensuring good pollination.

The trends illustrated in Figures 1 and 2 are typical of what occurred at all experimental sites. The implications and recommendations from these experiments are considered further in the Discussion.

Figure 1. Bee counts (mean of 15 observations) in Oct 1997 within a block of Royal Gala trees under white hail netting at Stanthorpe, Qld.

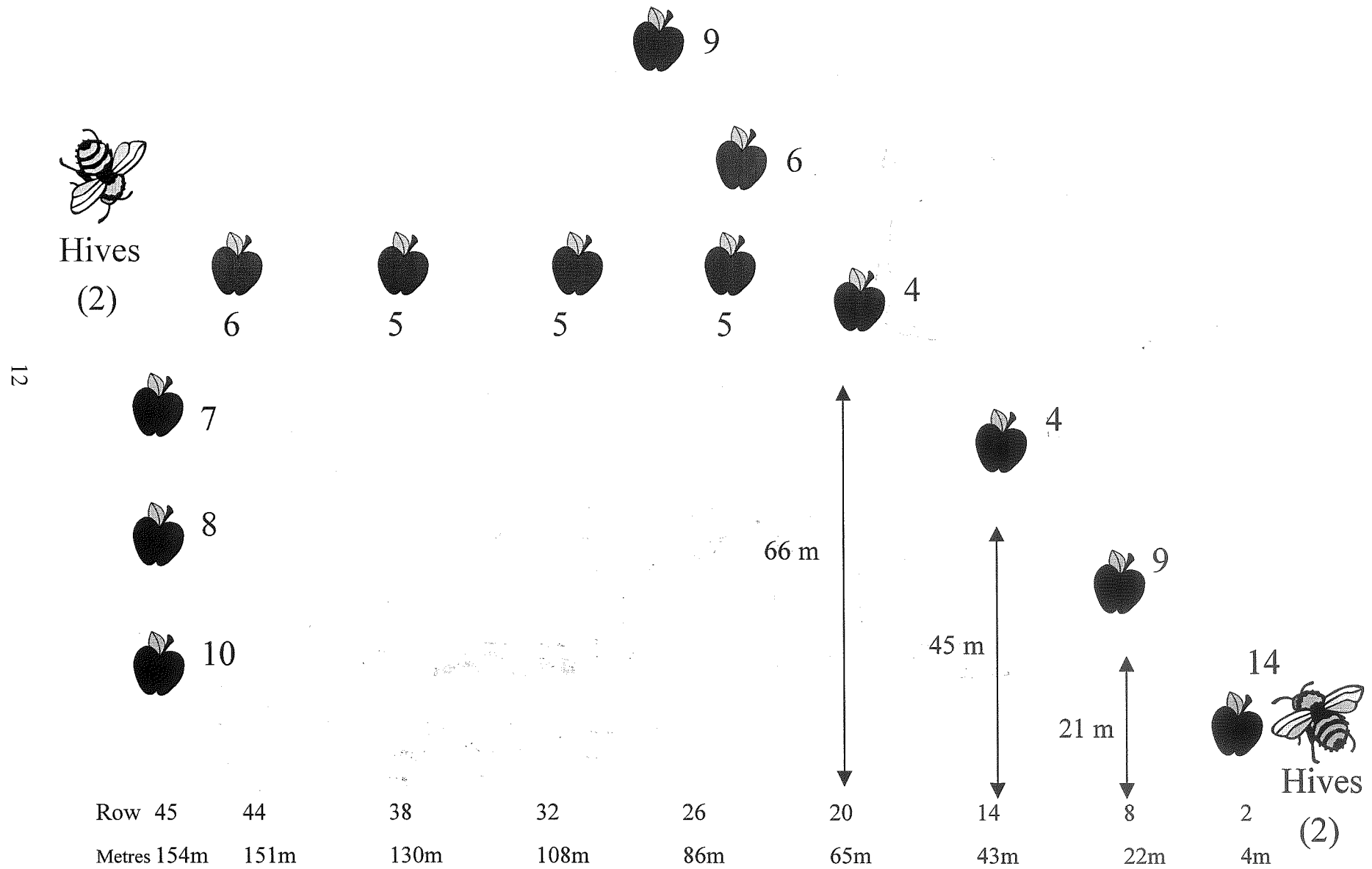
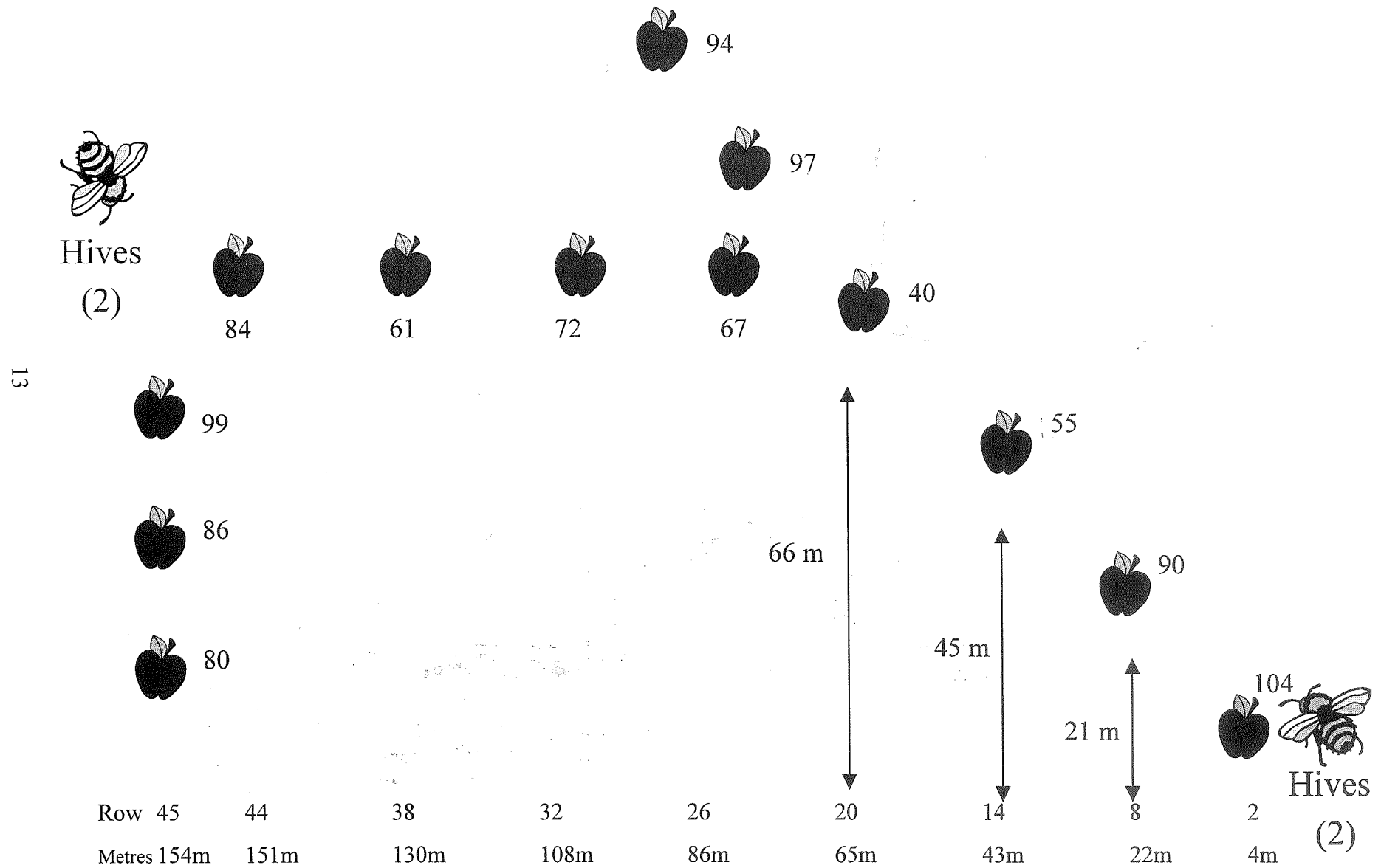


Figure 2. The fruit set / 100 flower clusters of Royal Gala trees under white hail netting in relation to their proximity to introduced bee hives.



Apple tree response to hail netting

Considerable data has been collected over several years from all trial sites, and it is impractical to include it all in this report. The results from these trials are summarised in Table 2.

Shoot growth on vigorous apple trees under hail netting was always greater than on identically pruned trees of comparable vigour grown outside the net. These effects were quantified by Middleton and McWaters (1996), and are considered in further detail in the tree management experiments outlined in this report.

Fruit set was always lower on trees under net (Figure 3), with fewer multiple fruit clusters occurring. At Orange, fewer chemical thinning sprays were used under hail netting, and at all trial sites less follow-up hand thinning was required on trees under net.

For comparable crop loads, Middleton and McWaters (1996) consistently measured smaller fruit on vigorous trees grown under netting than on similar unprotected trees. The production of smaller fruit on trees under net also occurred in this project (Figure 3), however this effect of net on fruit size was restricted to overvigorous trees. Where tree vigour was under control, as at sites 4, 5 and 6 on the Granite Belt, fruit on trees under net was of similar size or slightly larger than on uncovered trees (data not shown). The management of overvigorous trees under hail netting to maintain yields and fruit size was studied in further detail in the tree management trials (p17-28).

The incidence of fruit windrub, russet and sunburn is noticeably reduced by hail netting (Tables 3 and 4). For example, in April 1997, 21% of Granny Smith fruit numbers on uncovered trees at the Drouin site were sunburnt (9% severely), compared to 6% (1% severely) of fruit under net (Table 3). The occurrence of sunburnt fruit on the Granite Belt in 1998 was higher than this (36% of Fuji fruit numbers affected), with white netting reducing the sunburn incidence to 8% of the Fuji fruit (Table 3).

The reduced russet of apple fruit under net is demonstrated in Table 4. It is particularly noteworthy that the skin finish of Fuji (Nagafu 2) apples grown under hail netting on the Granite Belt is significantly improved under hail netting. Not only was russet reduced (Table 4), but the apples had a smoother skin and improved colour (Table 5).

Hail net can affect the fruit colour of red varieties, dependent on tree vigour and the location of apples within the tree canopy. Overvigorous trees with excessive shoot growth may internally shade fruit within the canopy and produce a higher proportion of poorly coloured fruit. By contrast, where tree vigour is well controlled, the colour of Hi Early apples on trees under black netting at Orange has been consistently better than on fruit from uncovered trees (Table 5). Similarly, Red Fuji (Nagafu 2) fruit from trees under netting at Applethorpe Research Station had superior colour to Nagafu 2 apples from adjacent uncovered trees (Table 5).

An additional benefit of hail netting is the reduction or elimination of bird damage to fruit, especially with hail net structures that are fully skirted to the ground. Effects of hail netting on fruit maturity and TSS were considered by Middleton and McWaters (1996).

Table 2. Apple tree response to hail netting, as compared to similar adjacent trees not covered by net.

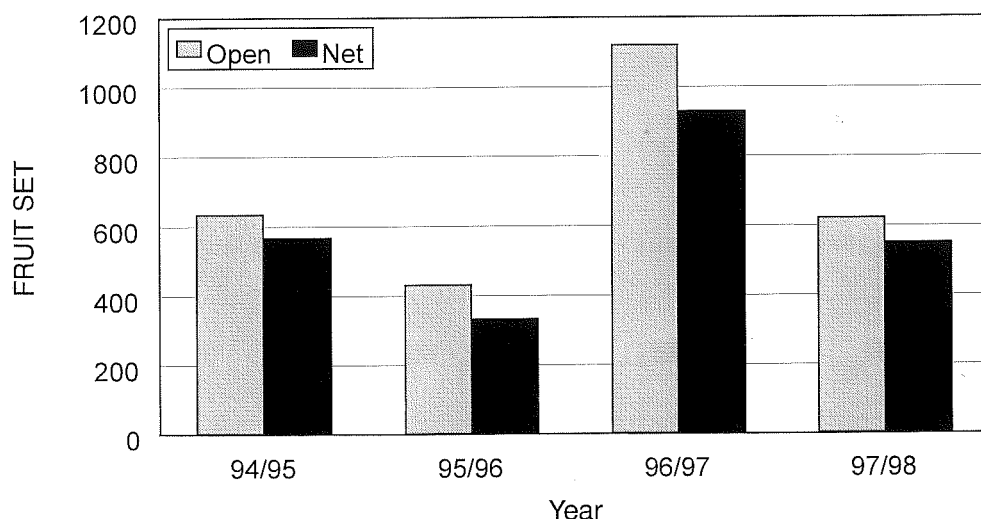
A. Tree Growth – response dependent on tree vigour

- : Shoot Numbers - Greater
- : Shoot Lengths - Longer
- : Leaf Size - Larger

B. Yield, Fruit Quality

- : Fruit Set - Reduced, fewer multiple clusters
- : Yield - Variable effect. Dependent on tree vigour, pollination
- : Fruit Size - Smaller on overvigorous trees
- Similar or larger on dwarf to semi dwarf trees, where vigour under control
- : Colour - Variable effect. Dependent on fruit position & tree vigour.
- : TSS - Reduced
- : Sunburn, windrub - Reduced
- : Russet - Reduced
- : Bird damage - Reduced or eliminated

Figure 3. Fruit set of vigorous Hi Early trees on N. Spy rootstock at Orange NSW (Site 2).



Yield (kg)	91	74	68	51	107	94	134	139
Fruit wt (g)	179	165	175	168	158	138	100	104

Table 3. Fruit quality under hail netting - fruit colour (% of fruit numbers).

Colour (Rating) *	1996 Hi Early (NSW)		1999 Hi Early (NSW)		1998 Red Fuji (Qld)	
	Open	Net	Open	Net	Open	Net
Excellent (4,5)	59	67	42	50	39	57
Satisfactory (3)	32	27	34	32	47	31
Poor (1,2)	9	6	24	18	14	12
Sample size	(8,000 apples)		(51,000 apples)		(6,000 apples)	

* Fruit colour ratings (1-5) for Hi Early are shown in Appendix I.

Table 4. Fruit quality under hail netting - russet incidence (% of fruit numbers).

Russet	1998 Red Fuji (Qld)		1997 Hi Early (NSW)		1997 G. Smith (Vic)	
	Open	Net	Open	Net	Open	Net
Severe	19	5	6.1	1.2	3.7	0.8
Moderate	21	13	n/a	n/a	n/a	n/a
Slight	31	45	n/a	n/a	n/a	n/a
0	29	37	n/a	n/a	n/a	n/a
Sample size	(11,000 apples)		(2,000 apples)		(13,000 apples)	

n/a – not assessed

Table 5. Fruit quality under hail netting – sunburn incidence (% of fruit numbers).

Sunburn	1996 Hi Early (NSW)		1997 G Smith (Vic)		1998 Red Fuji (Qld)	
	Open	Net	Open	Net	Open	Net
Severe			9.2	0.8		
Moderate+severe	7.8	0.7	21.1	6.4	36.0	8.0
Sample size	(8,000 apples)		(13,000 apples)		(11,200 apples)	

Tree management under hail netting

The pruning and crop load experiments at sites 1 and 2 were large scale trials conducted over three to six years. Due to space limitations and for ease of readability it has been necessary to exclude the data from many of the pruning treatment combinations described on pages 10 and 11. Nevertheless, the selection of results presented in this report cover the important findings from the tree management experiments.

Site 1 (Queensland)

The 1997/98 season was an 'on' year for the cropping of the Hi Early trees at this site. Dormant pruning of the trees in winter 1997 significantly reduced fruit set in that season (Figure 5), primarily due to a dramatic reduction in flower clusters (Figure 4) via the removal of potential fruiting wood. The trees unpruned in 1997 show a potential blossom load of nearly 1800 flower clusters (approximately 9000 flowers) per tree in that season (Fig 4). In 1997 there was no significant difference in the flower cluster counts of the winter-pruned trees, regardless of the intensity of pruning (Fig 4), with blossom counts in the range of 820 - 980 flower clusters per tree. In the two subsequent seasons, however, the flower production of the winter chunk (WIN Ch) pruned trees was much less than on the winter standard (WIN St) pruned trees. For example, the WIN Ch trees in 1998 had a mean blossom count of 420 flower clusters per tree compared to 700 - 720 flower clusters on the WIN St trees (Fig 4).

As outlined in the Materials and Methods, the five pruning treatments (Figure 4) were applied in the 1997/98 season. Winter chunk pruning (WIN Ch) removed on average 20 kg of wood (dry weight) per tree, and winter 'standard' pruning (WIN St) removed 12 - 14 kg (30 - 40% less) wood per tree. Summer chunk pruning (SUM Ch) removed an equivalent fresh weight of wood to the WIN Ch treatment, whilst the summer standard (SUM St) pruning in 1997/98 removed on average 2200 shoot leaves (equivalent to 5.0 m² leaf area) per tree.

In the 1998/99 season all trees were pruned exactly the same, according to a WIN St strategy that removed an average of 12 kg wood (dry weight) per tree. Hence the lower blossom counts and fruit set of the WIN Ch trees in 1998/99 and 1999/2000 (Figs 4 and 5) show that the effect of heavy winter chunk pruning in 1997/98 on flowering and fruit set still persisted for two seasons after the pruning was done.

The heavy crop load in 1997/98 suppressed shoot growth to the extent where the regrowth from heavily dormant pruned (WIN Ch) trees was no different to the standard dormant pruned (WIN St) trees (Table 6, compare treatments 1 and 4). In 1998/99 the combination of lower fruit set (Figure 5) and greater water availability meant that the shoot growth on all trees was greater than in the previous season, and also saw the 1998/99 shoot growth on the 1997/98 WIN Ch pruned trees significantly greater than that on the WIN St pruned trees (Table 6).

The 0 winter pruning treatment dramatically reduced current season shoot extension growth relative to the WIN Ch and WIN St treatments (Table 6), and this effect of 0 pruning persisted into the following (1998/99) season even when all the trees were WIN St pruned. With 0 pruning and a heavy crop in 1997/98, the trees spurred up and regrowth was minimal. Moderate winter pruning of these trees the following year was still able to keep vigour in check, despite the lower crop load.

Over two seasons the regrowth of the 0 prune trees totalled 244 metres, 35% less than the average 375 metres of shoot growth put on by the WIN Ch trees. Excessive watershoot production is a good indicator of overvigorous trees, and over two seasons the WIN Ch trees produced more shoots greater than one metre long than all other trees (Table 7).

Heavy summer chunk pruning in February 1998 (treatment 2) of trees that had not been pruned in winter 1997 still induced excessive shoot growth (209 metres per tree) the following season (Table 6),

even though the trees had spurred up and supported a heavy crop load (706 fruit per tree harvested in 1998/99). Despite the excessive shoot growth in 1998/99, SUM Ch pruning did not reduce fruit set relative to the unpruned trees, whereas WIN Ch pruning did (Figure 5, Table 8).

Light summer pruning (removal of 1 yo shoots) of WIN St trees in February 1998 had no significant effect on shoot growth, yield, crop load and fruit size (Table 6, compare treatments 4 and 5). WIN Ch pruning in 1997/98 reduced fruit set and yield for the two subsequent seasons relative to the SUM Ch and 0 prune trees (Figure 5, Tables 6 and 8). The fruit set reductions in Table 8 are particularly noteworthy. The larger mean fruit size of the heavily dormant pruned (WIN Ch) trees relative to the 0 prune and chunk summer-pruned (SUM Ch) trees can be attributed to their lighter crop load (Table 6). Indeed, much of the difference in average fruit weight between pruning treatments can be attributed to crop load. For example, the significantly smaller fruit on SUM Ch and 0 prune trees in both years was primarily due to their significantly heavier crop load (Table 6) than the other trees. The pruning x crop load interaction on fruit size will be considered further with the site 2 (Orange NSW) results.

Measures of fruit size distribution emphasise the high proportion of unacceptably small fruit on the 0 prune and SUM Ch trees in 1997/98 (Figure 6), due to their crop loads of >1000 fruit per tree. The mean fruit circumference (mm) and weight(g) for each treatment x year are indicated below the respective graphs in Figure 6. With lighter crops and greater availability of water in 1998/99, a higher proportion of the apples produced from all of the pruning treatments was of acceptable size and >70 mm diameter (Figure 6).

Figure 4. The effect of pruning on the flower production of vigorous Hi Early apple trees under black hail net (Qld)

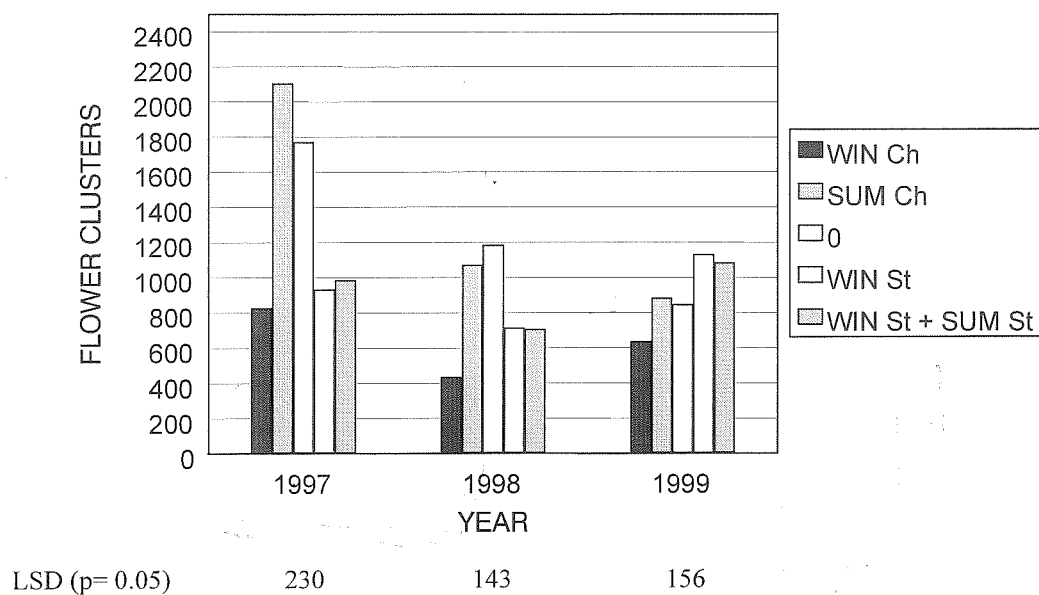


Figure 5. The effect of pruning on the fruit set of vigorous Hi Early apple trees under black hail netting (Qld).

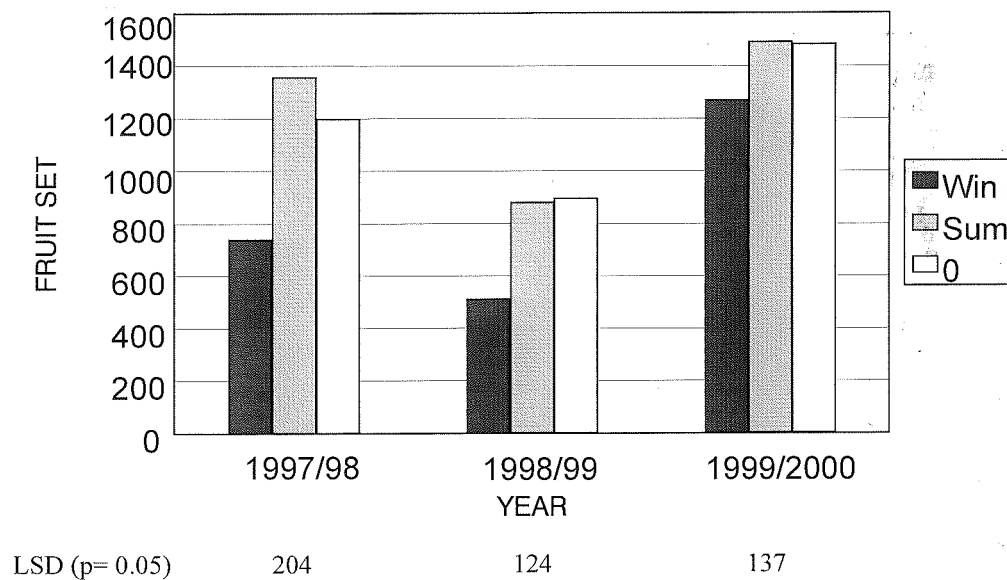


Table 6. The effect of pruning on the shoot growth and productivity of vigorous Hi Early apple trees under black hail net (Site 1 Qld).

	1997/98				1998/99				
PRUNING 1997/98	Shoot growth (m)	Yield (kg)	Av. fruit wt (g)	Fruit no.	PRUNING 1998/99	Shoot growth (m)	Yield (kg)	Av. fruit wt (g)	Fruit no.
1. WIN Ch	145a	109.7b	152.9a	723a	WIN St	230a	89.8b	177.5a	506a
2. SUM Ch	90b	133.5a	121.5b	1097b	WIN St	209a	111.6a	158.4b	706b
3. 0 prune	86b	144.0a	125.4b	1159b	WIN St	158c	111.7a	164.0b	681b
4. WIN St	134a	97.8b	156.6a	628a	WIN St	187b	85.2b	173.3a	496a
5. WIN St + SUM	136a (112)*	104.5b	151.3a	693a	WIN St	193b	91.7b	177.0a	523a

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

*Shoot growth figure in brackets shows the metres of shoot growth remaining after summer pruning in February 1998.

Table 7. The effect of pruning on the mean number of shoots >1 metre produced in two subsequent seasons by vigorous Hi Early trees under black hail net (Qld).

Pruning 1997/98	Shoot numbers >1 metre		TOTAL
	1997/98	1998/99	
1. WIN Ch	9 a	29 a	38 a
2. SUM Ch	0 b	24 a	24 b
3. 0 prune	0 b	13 b	13 c
4. WIN St	9 a	7 b	16 c
5. WIN St + SUM St	9 a (0.5)*	7 b	16 c

All trees were WIN St pruned in 1998/99.

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

Each figure is the mean of 9 trees per treatment.

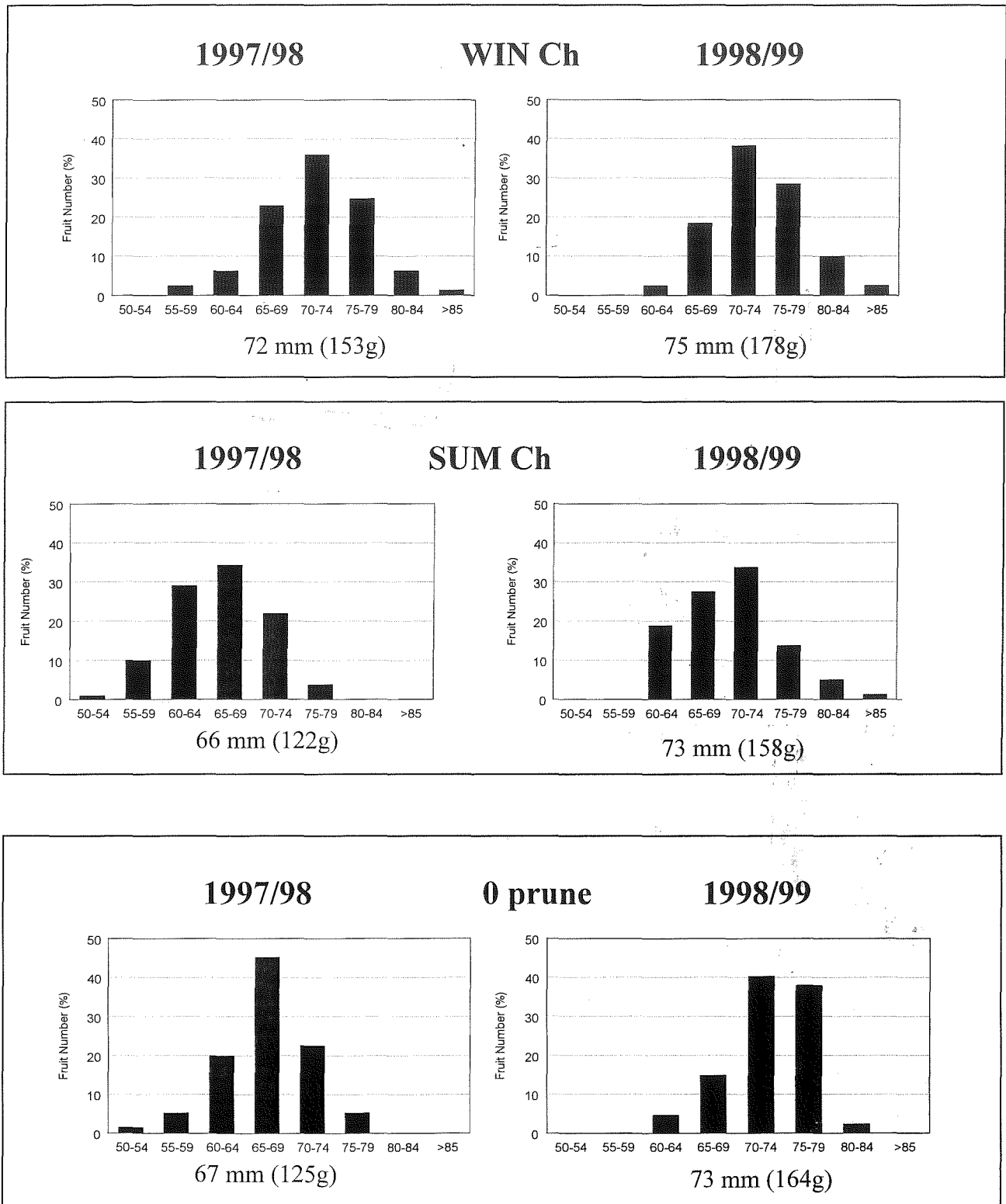
* Mean number of shoots >1 metre remaining after summer pruning in February 1998.

Table 8. The fruit set of vigorous Hi Early apple trees under black hail netting (Qld).

Pruning treatment		Fruit set/cm ² TCSA	
1997/78	1998/99	Nov 1997	Nov 1998
WIN Ch	WIN St	6.2 a	3.8 a
SUM Ch	WIN St	10.3 b	6.5 b
0 prune	WIN St	9.2 b	7.0 b

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

Figure 6. The effect of pruning on the fruit size distribution (5 mm size classes) of Hi Early trees under black netting (Qld).



Site 2 (Orange, NSW)

Several pruning and crop load experiments were conducted at this site over six years, and a selection of the more practically relevant results are presented in this report.

- *Experiment 1*

Heavy winter chunk pruning of vigorous Hi Early trees at site 2 in 1996 had no effect on flowering in that season, however in 1997 there was a dramatic decline in flower counts on the trees that had been winter chunk (WIN Ch) pruned for two successive years (Table 9). As a consequence of reduced flower production, the fruit set of WIN Ch trees in Nov 1997 was also dramatically reduced relative to WIN St trees (Table 9).

In this experiment, the restructuring of the trees was done by heavy WIN Ch pruning over two seasons (Table 9, treatment 1), with an average 17 kg wood (dry weight) per tree removed in dormant pruning in each year. As at site 1 (Qld), the WIN St trees (Table 9, treatments 2 and 3) were pruned to basically retain the existing tree structure. This pruning consisted of only one or two large (>5 cm diameter) cuts, up to 6 medium (2-3 cm diameter) cuts and up to 120 secateur cuts, which in total removed on average 12 kg wood (dry weight) per tree.

Following fruit set counts in November 1996, all trees in experiment one were hand thinned to the same crop load. Hence the fruit numbers harvested from all trees in March 1997 were similar (Table 10). At constant crop load, the average weight of apples harvested from the WIN Ch trees in March 1997 was 13 - 19 g less than from the other pruning treatments (Table 10).

The smaller fruit harvested from the WIN Ch trees would at least in part be due to the excessive shoot growth on these trees. Experiment 1 shoot growth data is not shown, but WIN Ch shoot growth was similar to the WIN Ch trees in experiment 2 (Table 11). Similarly, the excessive shoot growth on the WIN Ch trees in 1996/97 would have contributed to the reduced blossom and fruit set on these trees in October/November 1997 (Table 9) and the subsequent poor yield in March 1998 (Table 10).

As at site 1 in Queensland, the larger apples on WIN Ch trees in 1998 were due to the lower crop load (277 apples per tree compared to an average 778 apples per tree for the other treatments). Although not included in the statistical analysis, a single outlier WIN Ch tree that bore 702 apples (Table 10) demonstrates that at a crop load similar to (slightly less than) the WIN St trees, the average fruit weight of the WIN Ch trees was, as in March 1997, again likely to be lower than WIN St trees if the influence of crop load on fruit size had been eliminated by the standardisation of crop load. This was not done in this experiment so that a true measure of the effect of pruning on tree growth and productivity could be obtained.

Light summer pruning of WIN St trees in 1997/98 did not affect yield or fruit size relative to trees unpruned in 1997/98 (Table 10). A combination of WIN St, 0 and light summer pruning over two seasons maintained yields at 95 - 105 kg/tree/annum (Table 10), whilst minimising shoot growth. Summer pruning did however improve fruit colour (mean visual colour rating of 3.7 - refer to Appendix I) relative to the WIN Ch (3.2) and WIN St (3.3) treatments. Thus, the shoot regrowth and shading generated by the WIN St treatment under hail netting was sufficient to reduce fruit colour to a similar level to the more severe WIN Ch treatment. Apples on the 0 prune trees were generally of excellent colour (mean colour rating 3.7) as a consequence of minimal shoot growth and the heavy crop bending branches over so that fruit were in well-illuminated positions exposed to sunlight. The hail netting offered adequate sunburn protection to these fruit, as shown earlier in the Results (Table 5).

Table 9. The blossoming and fruit set of Hi Early trees under black hail netting (Experiment 1 - Orange NSW) as influenced by pruning.

Pruning		Flower clusters		Fruit set	
1996/97	1997/98	Oct 1996	Oct 1997	Nov 1996	Nov 1997
1. WIN Ch	WIN Ch	621	138 a	892	277 a
2. WIN St	0	548	897 b	838	833 b
3. WIN St	SUM St	519	881 b	846	787 b
		NS		NS	

NS – not significant

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

Table 10. The yield and average fruit size of Hi Early trees under black hail netting (Experiment 1 - Orange, NSW) as influenced by pruning.

Pruning		March 1997			March 1998		
1996/97	1997/98	Yield (kg)	Fruit no.	Av. fruit wt (g)	Yield (kg)	Fruit no.	Av. fruit wt (g)
1. WIN Ch	WIN Ch	90.1	665	135.5 a	44.6 a	277 a (702)	160.4 a (127.4)
2. WIN St	0	99.1	667	148.6 b	104.9 b	788 b	133.1 b
3. WIN St	SUM St	95.3	616	154.7 b	103.2 b	768 b	134.4 b
		NS	NS				

NS – not significant

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

- *Experiment 2*

The effect of pruning treatments on shoot growth is illustrated in Table 11. WIN Ch pruning in 1998 encouraged excessive shoot growth in 1998/99 that was twice as much annual growth than if the trees were left unpruned (Table 11). All trees were identically pruned (WIN St) in 1999, and despite this the latent effect of the previous years' WIN Ch pruning still saw significantly greater regrowth on these trees in 1999/00. 0 pruning in 1998/99 to slow annual shoot growth down was also successful in restricting shoot growth the following year when WIN St pruning was done.

Over the two seasons of experiment 2, the trees heavily dormant pruned (WIN Ch) in 1998/99 put on 434 metres of growth per tree compared to 257 metres on the trees unpruned in 1998/99 (Table 11). This 177 metre difference in growth and its effect on tree productivity is indicative of the significantly different physiological response between the 'unbalanced' WIN Ch trees and the better balanced 0 prune and WIN St trees. Much of the difference in shoot growth between the WIN Ch and 0 prune trees was due to increased shoot numbers (Table 11), although the shoots on the WIN Ch trees were also longer (data not shown). The WIN Ch trees had a greater propensity to overvigorous watershoot production, with an average of 27 shoots per tree >1 metre in the year of WIN Ch pruning, and 49 shoots per tree >1 metre in the year following heavy dormant pruning (Table 11).

Shoot growth under hail netting was always greater than on the comparably pruned trees outside the net (Table 11).

The yield reductions caused by WIN Ch pruning in experiment 1 were even more dramatic in experiment 2 (Table 12). The excessive shoot growth caused by WIN Ch pruning in 1998 led to a very dense, crowded canopy that shaded developing fruit buds and reduced yields to just 17.9 kg per tree in March 2000. In this particular experiment the trees were not hand thinned, hence Table 12 shows the effect of pruning treatments on yield and productivity without the confounding effect of adjusting crop load.

Despite an excessively heavy crop of small fruit in 1999 (880 - 950 fruit/tree), the 0 prune trees still yielded a satisfactory return crop in 2000 (Table 12). As with the other experiments, variations in mean fruit weight between treatments were largely a function of crop load, although as shown in experiment 1 it is likely there was also a direct effect of WIN Ch pruning on reducing fruit size.

As with shoot growth, the yield responses of trees under hail netting to pruning were more extreme than the uncovered trees, with the trees outside net showing less tendency to biennial bearing. For example, the yields of uncovered WIN Ch pruned trees averaged 60 kg/tree in both years of this experiment and the uncovered 0 prune trees ranged between 70 and 93 kg/tree over both seasons (data not shown), yet under hail netting the WIN Ch trees yielded 78 and 18 kg/tree over the two seasons, and the 0 prune trees 108 and 48 kg/tree (Table 12).

It is especially noteworthy that if the heavy chunk pruning of trees under netting was done in summer rather than winter there were no negative effects on tree growth and productivity (compare treatments 1 and 3 in Tables 11 and 12), and tree response to chunk summer pruning was no different to the unpruned trees that were WIN St pruned in the following year (Tables 11 and 12).

- *Experiment 3*

Crop load experiments at Orange NSW have highlighted the effect of pruning, crop load and hail netting on shoot growth. Table 13 summarises some of the results from this work.

Shoot growth declined as crop load increased, regardless of the pruning treatment or the presence or absence of hail netting. When crop load was standardised, the shoot growth of WIN Ch trees was always greater than the unpruned trees. For example, at a crop load of 717 apples/tree the shoot growth of WIN Ch trees was 134 metres compared to 88 metres for unpruned trees bearing 735 apples (Table 13). Similarly, the shoot growth of trees uncovered by net tended to be less than trees of comparable crop load under hail net (Table 13). The increased shoot growth of vigorous trees under hail netting also occurred in experiment 2 (Table 11), and was reported by Middleton and McWaters (1996).

It is therefore essential to consider the response of trees to hail net in terms of their crop load and the pruning strategy used, as the pruning x crop load interaction will determine how tree growth and productivity respond to the hail netted environment.

Middleton and McWaters (1996) documented the effect of hail netting on fruit size. Semidwarf and dwarf trees grown under hail netting on the Granite Belt produced similar size or larger apples than comparable trees outside net, whereas smaller fruit were produced on overvigorous trees under hail net as compared to similar uncovered trees. The tendency for overvigorous trees to produce small fruit under net can be reversed through attention to tree vigour control and pruning strategy. A combination of judicious pruning and crop load manipulation over three years allowed full advantage to be taken of the protected hail net environment with vase-pruned Granny Smith trees at Drouin, Victoria. At all crop loads, fruit were larger under net (Table 14), thereby reversing the trend that had occurred at this site previously. As expected, average fruit size declined as crop load increased. Average fruit weight under net was 14 - 19 g/fruit greater than on comparable uncovered trees, thereby demonstrating that large fruit can be produced on big trees under net, provided tree vigour is controlled.

Table 11. The shoot growth of vigorous Hi Early trees under black hail netting (Exp 2 - Orange, NSW) as influenced by pruning.

Pruning		Shoot growth (m)		Shoot number		Shoots >1m	
1998/99	1999/00	1998/99	1999/00	1998/99	1999/00	1998/99	1999/00
NET							
1. WIN Ch	WIN St	211 a	223 a	443 a	409 a	27 a	49 a
2. 0	WIN St	104 b	153 b	249 b	330 b	13 b	19 b
3. 0 + SUM Ch	WIN St	56 c	177 b	157 c	370 a	3 c	22 b
OPEN							
1. WIN Ch	WIN St	174 a	183 b	451 a	382 a	12 b	21 b
2. 0	WIN St	80 c	125 c	268 b	297 b	0 c	6 c
3. 0 + SUM Ch	WIN St	72 c	124 c	228 b	278 b	0 c	6 c

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

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Table 12. The yield of vigorous Hi Early trees under black hail netting (Exp 2 - Orange, NSW) as influenced by pruning.

Pruning		Yield (kg)		Fruit number		Average fruit weight (g)	
1998/99	1999/00	1999	2000	1999	2000	1999	2000
1. WIN Ch	WIN St	78.5 a	17.9 a	634 a	115 a	123.9 a	155.7 a
2. 0	WIN St	108.3 b	47.8 b	951 b	335 b	113.8 b	142.7 b
3. 0 + SUM Ch	WIN St	102.4 b	59.1 b	882 b	424 b	116.1 b	139.4 b

Means in a column followed by the same letter are not significantly different ($p = 0.05$).

Table 13. The effect of hail netting and crop load on the shoot growth (1998/99) of vigorous Hi Early apple trees at Orange, NSW (Experiment 3).

Pruning	Net		Open (uncovered)	
	Crop load	Shoot growth (m)	Crop Load	Shoot Growth (m)
WIN Ch	526	157.5	456	127.3
	604	148.6		
	717	134.4		
0	546	108.6	499	78.7
	636	106.3		
	735	88.4	883	81.2
	1025	53.5		

Table 14. The effect of hail netting and crop load on the average fruit weight (April 1999) of Granny Smith trees at Drouin, Vic.

Crop load (Fruit/cm ² TCSA)	Average fruit weight (g)	
	Net	Open (uncovered)
2.6	177	162
3.7	161	147
4.2	152	133

DISCUSSION

Bee activity trials

Bee foraging behaviour is complex and influenced by many factors, including weather conditions (light, temperature, wind), time of day, floral stage and 'attractiveness', types of bees (pollen or nectar collector; top or side-worker), the proximity of alternative floral sources, hive density and arrangement (Gary 1975; Middleton *et al.* 2000). It is essential when covering an orchard with hail netting that these factors are considered in order to take full advantage of the environment beneath hail netting and to ensure adequate cross-pollination.

The introduction of honeybees into apple orchards is a common practice to help manage adequate cross-pollination and fruit set, but can be somewhat taken for granted. A foraging bee's primary objective is to obtain pollen and nectar, and the pollination of apple trees is purely the side benefit that orchardists obtain from bees' foraging activity in the orchard. Observations of bee activity made in this project at many sites since 1996 highlight several key points in the management of bees under hail netting. These are discussed in further detail by Middleton *et al.* (2000).

Hive strength

Weak hives contribute nothing to the pollination of the crop. It is essential to the orchardist and the beekeeper that the hives remain strong. Strong hives consist of about 60,000 bees nurturing up to eight combs of brood (Martin 1975). The brood (developing bee stages) provides the stimulus for the foraging behaviour in honeybees. In addition, if the field bees are not replaced by a constant supply of younger bees, the numbers of bees in the hive will quickly dwindle. Martin (1975) discusses hive strength and the pollination of crops by honeybees in greater detail.

Place hives under hail netting to ensure adequate pollination

Generally, bees are less inclined to fly into orchard blocks covered by hail netting than into blocks of uncovered trees (Middleton and McWaters 1996). It is therefore advisable to distribute the hives throughout the netted orchard to ensure an even distribution of foragers. The further that bees forage in the block, the greater is the likelihood of adequate cross-pollination. Positioning hives either singly or together in small groups throughout the orchard will help to ensure an even distribution of bees throughout the block. An adequate stocking rate of hives per hectare increases the competition between hives and encourages bees to work further afield in the block.

The degree that hives are distributed depends to a large extent on the prevailing weather during flowering. For southern Victoria, where periods of inclement weather during blossoming can restrict bee activity to short flights, hives should be positioned so that no tree is further than 150 metres from a hive (Goodman and Middleton 1999). In warmer climates it may be possible to apply greater distances than those suggested for southern Victoria, although the measured decline in bee activity and apple fruit set with increasing distance from the hive at a Qld site (Figs 1 and 2) suggests that the 150 metre distance is a reasonable guide.

Bees must be introduced under hail netting once flowering has commenced, usually at about 3-5% bloom and when there is sufficient attractive blossom to exploit. Any delays in the introduction of hives can adversely affect fruit set. Bees work flowers to obtain protein (pollen) and carbohydrate (nectar). Early introduction of hives before flowering will only encourage bees to seek alternative nectar and pollen sources outside the netted area. It is then possible for the bees to 'lock-on' to this alternative source and not satisfactorily pollinate the intended target crop.

Adequate space between the top of the trees and the hail net is essential for optimum bee flight

Where there is little or no gap between the tree top and the net, bees are unable to fly freely and an uneven distribution of bees may occur within the block of trees. The bees will then prefer to forage along the rows. This will have a particularly adverse effect on cross-pollination if polliniser trees are planted in separate rows to the main variety. The problem of obstructing bee flight may be further compounded if the hail netting structure is of peaked (gable) design and the tree tops are growing up into the apex of these peaks.

Bees naturally tend to work along tree rows, however the more protected environment under netting as compared to uncovered trees can encourage increased bee foraging across alleyways and between adjacent tree rows. Full advantage should therefore be taken of this beneficial effect of hail netting by ensuring that bee flight in the orchard is not obstructed by trees growing too close to the hail net cover.

Trapped bees

When newly introduced under hail netting, bees may become disorientated and trapped in the apex or gables of the netting structure. They eventually die, and other adult bees that take up foraging duties appear to acclimatise to the environment and are able to find their way back to the hive. This is not generally a problem in structures where the net is flat. Bees may also become trapped in the net itself.

Temporary removal of netting during flowering

Temporary removal of the hail netting, or sections of it, during flowering is one means of achieving optimum pollination. Bees are able to fly upwards and out of the hail net environment, and then fly back down to the target trees. The temporary removal of netting during blossoming is largely impractical on the Granite Belt, Qld, where 'fixed' net structures are in place. Nevertheless, if persistent pollination problems occur in a particular block of trees, it may be worth considering ways to temporarily remove some runs of net during the flowering period, as well as allow for this facility in the erection of subsequent hail netting support structures.

Temporary net removal is a standard management practice in NSW (Batlow and Orange), where hail netting is rolled up over winter to prevent the weight of accumulated snow collapsing the support structure. To facilitate bee activity and cross-pollination it is suggested that either the unfurling of the hail net is delayed until after the end of flowering, or alternatively only every second run of net is unrolled, at or prior to flowering. Growers also need to consider the incidence of spring storms and the risk of hail damage to flowers when implementing these strategies.

Opening the hail net covering during flowering will help to:

- Increase light levels within the netted area and thereby encourage bee activity.
- Facilitate bee access to the trees and allow bees to forage across blocks.
- Reduce the bee numbers trapped in the net.

Fully enclosed blocks

Many hail net structures are fully 'skirted' and completely enclosed down to or almost down to ground level. Such enclosures eliminate bird damage to fruit and protect the fruit on trees growing at the edge of the block from wind-driven hail. When hives are first introduced to a fully enclosed environment, some of the field bees may fly against the cloth and become trapped whilst foraging. Bees introduced into any new locality will scout out the available food sources and the net can be a physical barrier to this. Trapped bees soon die and are replaced by younger bees that have acclimatised to the conditions under the hail net.

Apple tree response to hail netting

The effect of hail netting on apple tree growth, yield and fruit quality is largely determined by tree vigour. Fruit quality and yield can vary considerably within the apple tree canopy, and exposure to light is a major factor contributing to this variation (Jackson 1980). Indeed, on overvigorous trees, poor fruit set and fruit quality will occur regardless of the presence of netting.

The increased shoot growth, larger leaves and reduced fruit set of vigorous trees under black net at Orange, NSW and Drouin, Vic are classic 'shading response' symptoms that did not occur with semi-dwarf and dwarf trees under hail net on the Granite Belt, Qld. Fruit set reductions have not been large (Figure 3) but are significant enough to provide beneficial scope to reduce hand thinning. This is considered further in the tree management experiments.

Lower fruit set under net is likely due to a combination of factors, including (a) the influence of reduced light on spur quality and fruit bud differentiation, (b) improved efficacy of chemical spray thinning and (c) effects of net on bee activity and pollination. It was particularly noticeable during flower counts at the Orange site that not only was there less blossom under net, but that full bloom of these trees was several days later than the uncovered trees. From observations of bee activity made in Granite Belt orchards, the timing of the introduction of hives under hail netting with respect to tree floral stage is critical. As discussed previously, the introduction of hives under net when blossom is unattractive to bees will only encourage them to seek pollen and nectar from sources further afield, without adequately pollinating the trees nearby.

Hail netting had little effect on total yields, except at the Orange, NSW site where Hi Early trees under net yielded less than the uncovered trees for three consecutive years (Figure 3). Despite lower initial fruit set, the average fruit weight of apples under net at Orange was 14g (1995), 7g (1996) and 20g (1997) below that of apples from uncovered trees (Figure 3). Shoot growth of the trees under net was excessive, and under conditions of adequate water photosynthates seemed to be directed into shoot growth rather than fruitlet development. Indeed, changes in tree pruning and crop load regulation strategies made in 1997/98 improved the yield and fruit size of apples from overvigorous trees under hail netting relative to the uncovered trees (Figure 3, compare 1996/97 and 1997/98). These changes are further discussed in the tree management experiments (Orange, experiment 1).

The magnitude of hail netting effects on tree growth and productivity will vary depending on tree vigour, pruning and crop load. The effect of hail netting on tree growth, yield and fruit size is minor on smaller trees. Where vigour is under control, apples on dwarf to semi dwarf trees are either of similar size or larger under net compared to uncovered trees. This is most likely due to improved water use efficiency through lower evapotranspiration under net (Kon *et al.* 1989). Such a beneficial effect of netting may disappear if trees are injudiciously pruned heavily, thereby encouraging excessive shoot growth.

Any effect of hail netting on the mean fruit size of vigorous trees is to a large extent determined by the fruit size distribution within the tree canopy. Shading within apple trees reduces fruit size and colour with increasing depth in the canopy (Middleton 1990). On the vigorous four to five metre tall vase-pruned Granny Smith trees at Drouin, Vic (Site 3), the lower average fruit weight of apples under net was due to the higher proportion of the crop occurring between 1 and 2 metres above the ground (Middleton and McWaters 1996). At this height the cumulative shading effect of the hail net and the leaf canopy together reduced fruit size on the trees under net relative to apples produced 1-2 metres above the ground on the uncovered trees. At all other heights there was no effect of netting on fruit size. Above a height of two metres, light levels were adequate for fruit size development regardless of the presence of netting. Similarly, below one metre there was insufficient light for fruit set or fruit size development with or without netting, and only 1-2% of the total crop was borne in this zone. Changes to pruning and crop load distribution of these trees in the tree management experiment led to the production of larger fruit under net (Table 14).

Incident light levels in Australia are high relative to other apple growing regions of the world, and it is of significance that on fine clear days between late November and late January, incident PAR levels in Victoria are similar to the Granite Belt, Queensland (Middleton and McWaters 1996). PAR (photosynthetically active radiation) is visible light of wavelengths 400-700nm that is intercepted and utilised by trees in the process of photosynthesis (Jackson 1980; Middleton 1990). Heavy cloud cover and the apple tree canopy itself can rapidly deplete PAR to levels that severely impact on potential orchard productivity, most especially when trees are excessively vigorous. It is in these circumstances that the 12 to 27% light reductions by hail netting are sufficient to reduce yields and fruit size through both a direct effect on light levels, and the indirect effect of excessive vegetative growth in response to winter pruning and net-induced shade levels. Tree vigour control under hail netting is therefore essential.

Although hail netting has relatively little influence on total yields, there is a significant increase in packout (marketable yield) through reductions in sunburn and russet, improvements in colour and the reduction or elimination of bird damage to fruit.

Improvements in the fruit colour of red apple varieties grown under hail net occurred consistently (Table 3), provided tree vigour was under control and not excessive. Due to internal shading effects on fruit set, a higher proportion of apples grown under hail net tended to occur in 'well-illuminated' parts of the tree where fruit colour development was not adversely affected by shade. Hence a greater proportion of the cropping zone of trees under net was towards the periphery of the canopy, in parts of the tree favouring good fruit colour development.

It is also suggested that the higher proportion of diffuse (scattered) light occurring under net would favour good fruit colour development. The scattering of incident light as it strikes individual strands in the net and passes through to the trees below means that light penetrating the tree canopy is coming from a greater range of angles of incidence than that which penetrates trees not covered by hail netting. Hence, the pattern of light penetration within trees under net may be better than what would occur from the direct solar beam where there is far less scattering of light and more clearly defined regions of light and dark (shade) in the canopy. Light levels within the canopies of trees under and outside hail netting were measured and reported by Middleton and McWaters (1996).

The incidence of fruit russet under net was markedly reduced (Table 4) and the skin finish of Fuji in Queensland improved, with fruit typically characterised as smooth and unblemished. The dull brown hue often seen on Fuji fruit produced in Queensland was minimal under net, and the incidence of severe russet reduced from 19% of fruit numbers to 5%. The incidence of sunburn on apples was also dramatically reduced at all sites by hail netting (Table 5). One of the major advantages of apple production under hail net is that dwarf and semi-dwarf high density production (hdp) systems are particularly suited to hail net protection. Such systems are based on shorter (2-3 metre high) trees with reduced leaf canopy and a fruiting zone exposed to high sunlight levels. Hail netting facilitates the production of apples by hdp systems, with fruit located on exposed parts of the tree which would otherwise be prone to sunburn without the presence of netting.

The reduction or total elimination of bird damage is an often underestimated benefit of hail netting, which in itself in some areas may make netting an economic proposition regardless of the seasonal incidence of hailstorms. Given the protected status of many of the species of Australian birds and parrots that feed on or damage apple fruit, and the ineffectiveness or undesirability of alternative methods of bird control, the use of hail netting for bird control may increase in the future. Hail netting of up to 2000 hectares of orchards on the Granite Belt has now seen an increasing emphasis on the production of late-season varieties which in the past would have been devastated by birds.

Tree management under hail netting

Hail netting is a significant investment in orchard productivity. It is therefore essential to use any beneficial effects of netting to greatest advantage, whilst at the same time minimising any adverse effects.

The tree management experiments demonstrate how pruning and crop load can markedly influence apple tree response to hail netting. The control of tree vigour under hail net is essential. Prior to the control of tree vigour through pruning and crop load manipulation, apple yield and fruit size on overvigorous trees under net was generally lower than on comparable trees outside net. Pruning of excessively vigorous trees under hail netting must aim to minimise regrowth, and thereby maximise yield and fruit size.

Apple trees where vigour is under control, such as trees on dwarf or semi-dwarf rootstocks, may produce larger fruit under hail net (Middleton and McWaters 1996). Pan evaporation in a Japanese pear orchard under hail net was reduced by an average 1 mm per day (Kon *et al.* 1989). Lower evaporation of at least this magnitude can be expected under hail netting in the relatively warmer conditions in which apples are grown in Australia, as a consequence of reductions in windspeed and incident sunlight (radiant heat). In the relatively dry Australian environment, it is essential that any increases in available water as a consequence of hail netting are used to maximum efficiency, and are hence directed to and utilised by developing fruitlets (during the six weeks after bloom in cell division, and thereafter in cell enlargement) rather than in the production of excessive shoot growth.

Overvigorous trees under hail net will produce smaller apples than comparable trees outside net if additional available water is directed into shoots rather than fruit, however this trend can be reversed through judicious pruning and tree management. Larger fruit were produced on vigorous trees under net (Table 14) once tree vigour was kept under control. At all sites the 0 winter pruning treatment dramatically reduced shoot extension growth, and heavy chunk dormant pruning encouraged excessive shoot growth the following spring (Tables 6, 7, 11). More significantly, the crop in the second year after this drastic pruning treatment was still much lower than on trees that were either unpruned or had been heavily chunk pruned in the summer instead of winter (Tables 6, 10, 12). Summer chunk pruning did not reduce fruit set in subsequent seasons, whereas chunk pruning done in winter did.

The shoot growth of overvigorous trees under net was always greater than on similarly pruned uncovered trees (Tables 11, 13), and this needs to be considered when managing overvigorous trees to maximise yield and fruit size.

At sites 1 and 2, heavy dormant chunk pruning (WIN Ch) of the overvigorous Hi Early trees in just a single season was sufficient to throw out the vegetative and reproductive balance of the trees (in terms of shoot growth, blossom, fruit set and yield) for at least two seasons. Heavy chunk pruning in winter was not desirable, especially if done prior to a lighter crop load ('off') season (1997/98 and 1999/00 in NSW). The excessive regrowth caused by WIN Ch pruning is likely to have reduced tree productivity indirectly through shading effects on bud strength, fruit set, fruit size and colour, and directly via source/sink mechanisms.

The response of hail-netted trees to heavy WIN Ch pruning tended to be the production of excessive shoot growth the following spring, which in turn dramatically reduced flower production, fruit set and yields in the season after that (Figures 4, 5; Tables 6, 8, 9, 10, 12). This established a severe biennial bearing pattern with very low yields in the 'off' year.

Fruit size differences between pruning treatments can largely be attributed to crop load, rather than a direct effect of the pruning treatment itself. Hence, the larger fruit on the WIN Ch trees was primarily due to their significantly reduced crop load. Indeed, if the crop load of the WIN Ch trees was adjusted

to that of the other pruning treatments, there was a tendency for the WIN Ch trees to produce smaller fruit (Table 10).

Overvigorous trees left unpruned (0 prune) and unthinned for one season appeared unsightly, with minimal regrowth and spindly over-cropped branches bent over with heavy crops of apples. Standard dormant pruning of these trees in the subsequent season tidied up their appearance, but more importantly generated sufficient younger renewal wood without excessive debilitating regrowth to upset tree growth, balance and productivity. With 0 pruning followed by minimal pruning, the trees spurred up and 'weakened' (despite their high vigour), and the cropping zone was pushed to outer and upper parts of the tree which were relatively 'well-illuminated' zones producing large fruit. The effect of fruit position on fruit size was considered in detail by Middleton and McWaters (1996). The sacrifice of some of the crop in the year the trees were left unpruned saw tree balance and productivity improved in subsequent years, without the biennial bearing habit and excessive vigour that occurred with heavy dormant chunk pruning.

It is essential to consider the response of trees to hail net in terms of their crop load and the pruning strategy used. The results from this project show that the pruning x crop load interaction determines how tree growth and productivity responds to the hail netted environment, and that heavy winter pruning must be avoided on overvigorous trees under net.

A pruning x crop load strategy for vigorous trees under hail netting should aim for a balance between tree vigour (ideally <150 metres shoot growth annually; all shoots <75cm), crop load, fruit size and biennial bearing (0 or slight). On mature 15 year old Hi Early Red Delicious trees in Qld and NSW this was achieved with a crop load of 400-500 fruit/tree (3.0-3.5 apples/cm² TCSA) and a pruning strategy of 0 or light winter pruning, followed by light or chunk summer pruning. This pruning strategy done over two seasons at Orange maintained yields at 95-105 kg/tree/annum (Table 10) whilst minimising excessive shoot growth.

The consistently lower fruit set of trees under hail net offers a potentially significant advantage in reduced thinning costs, provided tree vigour is kept under control and fruit size is maintained. Trees under hail net at Orange were not spray-thinned in 1999/2000, whereas trees in the open received two sprays (NAA and Cylex). In previous years trees under net received two chemical thinning sprays and required minimal follow-up hand thinning, whilst trees outside the net received three chemical thinning sprays and required significant follow-up hand thinning. Observations made on the Granite Belt, Queensland, also concur that tree response to thinning sprays is better under net. The higher humidity and reduced wind under hail net can be expected to contribute to an increase in chemical thinning efficacy through a twofold effect : (a) slower drying times that permit improved chemical absorption by leaves, and (b) permitting timely spray applications under windy conditions that would otherwise prevent the spraying of uncovered trees. These principles would also apply to pesticide and fungicide sprays.

Orchards protected by hail netting need to rapidly attain and maintain high yields and packouts to recoup the cost of the netting and support structure. High-yielding intensive systems for apple production using dwarf or semidwarf rootstocks that control tree size and encourage early cropping are ideally suited to this purpose. Hail netting makes it essential to produce the highest possible yields of premium quality fruit, and minimise production costs and wastage. It is only with control of tree vigour and attention to pruning and crop load that this can be ensured.

ECONOMIC ANALYSES

A cost-benefit analysis, with a discount rate of 8%, was used to calculate the expected profitability of hail netting in Queensland, NSW and Victoria. The profitability criteria calculated were Equivalent Annual Return (the annualised Net Present Value), Internal Rate of Return and Discounted Payback Period.

The analyses took into consideration the secondary benefits of hail netting, such as reductions in sunburn and bird damage to fruit. For the Granite Belt the analyses were partly based on the probability distribution of hailstorms, and risk analysis was incorporated to account for the uncertainty of hailstorms. Insufficient historical hailstorm data were available, so the probability distribution was developed from a survey of experienced growers on the Granite Belt.

The economic analyses are described and discussed in further detail by Whitaker and Middleton (1999). The objectives of the study were to assess:

- the profitability of hail netting.
- the minimum annual losses to hailstorms to justify hail netting.
- the sensitivity of profitability to changes in the cost of hail netting, yield, packout and market price for apples.

Scope and limitations

As with any economic analysis, many assumptions had to be made, and these are listed and described in detail by Whitaker and Middleton (1999). The calculations were based on the following data:

- The timeframe for the analysis was set at 24 years, this being twice the life expectancy of the netting. The life expectancy of the structure was 40 years.
- The hail net was first established when the apple trees were two years old, this being the first possible year of apple production. Trees were replaced after their 15th year.
- Management practices under netting were adapted to maximise productivity.
- The analysis is for one hectare with a planting density of 1 000 trees per hectare.
- Other than the costs directly associated with hail netting, establishment costs do not vary between apple orchards without and with hail netting.
- Production costs were similar between regions;
- Apples are sold through their local market;
- Taxation and financing arrangements have not been included.
- The impacts of new technologies do not vary between orchards that have or do not have hail netting.
- No allowance was made for damage to the crop from a collapse in the hail netting.
- There were no price effects resulting from increased production.

Of particular note is that for practicality, four aspects of hail netting were not costed in the analysis:

- Taxation and financing arrangements
- The potential to supply a consistent quantity and quality of apples and thereby maintain relationship with buyers (a grower benefit)
- 'Peace of mind' (a grower benefit : what is it worth to have a good night's sleep?)
- The availability of fresh apples despite hailstorm activity (a consumer benefit).

For simplicity it was assumed that all fruit were sold through their local market. Assumptions were made regarding the yields and packouts of different apple varieties with and without hail net, the benefits and costs of hail netting, and the variable costs of apple production, which were based on Sevil and Smith (1997). The assumptions are provided in more detail by Whitaker and Middleton (1999). Dollar values used for all of these parameters will influence the results of the analyses. Because of this, a spreadsheet was also designed into which different values for the parameters particularly relevant to an individual grower could be inserted, and their effect on hail netting profitability determined. A sample spreadsheet is included in Appendix II.

The prices used in the analyses were based on the fresh apple prices at the Brisbane, Flemington and Melbourne markets from 1994 to 1998. Prices can vary significantly between different apple varieties and markets, as shown in Table 15. The average prices ranged from a low of \$16.02 per case (Delicious in Queensland) to a high of \$41.35 per case (Pink Lady in Victoria).

Table 15. Five-Year (1994-1998) average real apple prices, by variety

Variety	Average Price (\$/case)		
	NSW	VIC	QLD
Average	20.27	24.33	18.59
Delicious	17.66	23.64	16.02
Granny Smith	19.29	20.89	19.32
Fuji	29.26	26.07	28.51
Pink Lady	35.75	41.35	31.26
Gala	29.18	36.15	28.53

Source: Ausmarket Consultants 1999

With the exception of Granny Smith apples, prices received at the Sydney and Melbourne markets were consistently higher than those at the Brisbane market. The average price for processing apples was estimated at \$150 per tonne for all apple varieties.

Deterministic analyses

A deterministic analysis was conducted for each variety x State combination. This analysis assesses the minimum hail losses required to justify hail netting. The profitability of hail netting was calculated using the full range of possible hail events, from no losses attributed to hail to 100% loss of 1st grade fruit from hailstorms. A simulation based on the probability distribution function for hail events on the Granite Belt was also conducted for each variety in Queensland.

The results of the deterministic analyses are presented in Figures 7, 8 and 9.

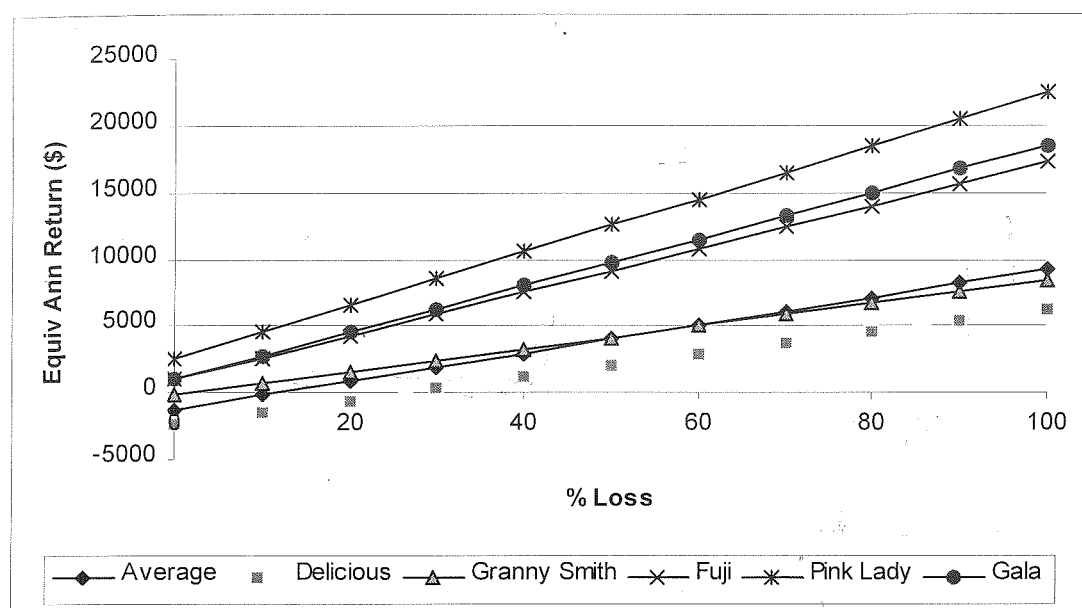


Figure 7. Profitability of hail netting, New South Wales

For the average orchard in NSW, hail netting was profitable as long as the minimum annual loss to hailstorms was at least 13% of first grade apples. In the absence of any damaging hailstorms (Annual Loss is 0 per cent), the equivalent annual return (EAR) was -\$1,272 per hectare. The profitability of hail netting increased with increasing annual loss.

Delicious apples were the least profitable to hail net, and required annual losses to hailstorms of at least 27% of first grade apples to be profitable. Without any hail damage, the EAR was almost -\$2,300 per hectare. This increased to \$6,300 per hectare for annual crop losses of 100 per cent of first grade apples.

Hail netting of Granny Smith apples was profitable with just minimal losses due to hailstorms. With no losses due to hailstorms, the EAR was -\$145 per hectare. Positive returns were achieved when annual loss to hailstorms was 2% or more of first grade apples.

Fuji, Pink Lady and Gala apples were all profitable to hail net, irrespective of any effects arising from hailstorms. With no annual losses due to hailstorms, the EAR for Fuji apples was \$983 per hectare, \$1,026 for Gala and \$2,489 for Pink Lady. The good result for Pink Lady is due to the high price it received at the Sydney markets. While the price for Fuji apples was slightly higher than that for Gala, the Gala apples were slightly more profitable to hail net due to higher packouts, with or without netting.

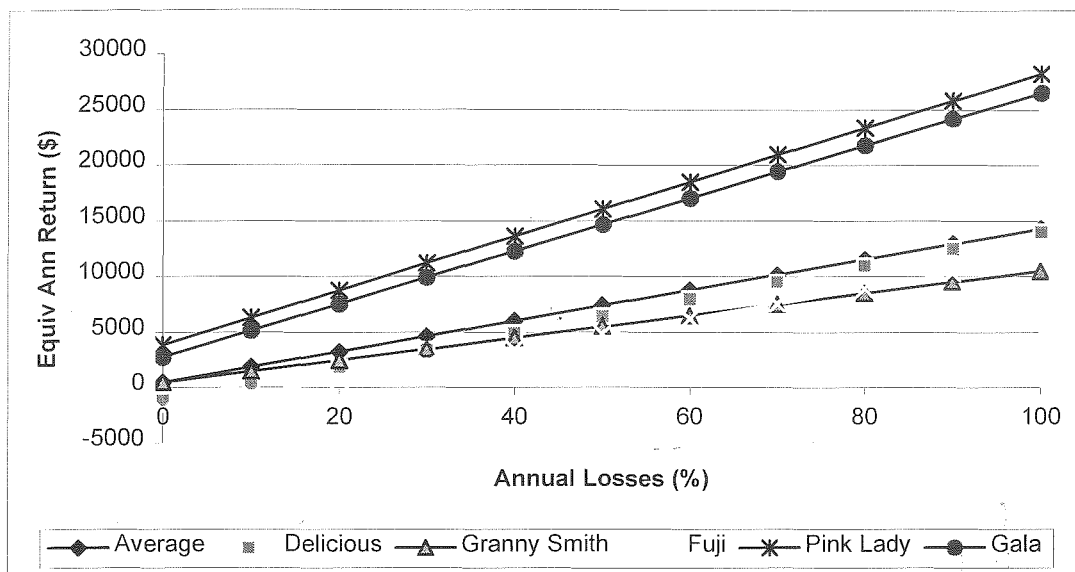


Figure 8. Profitability of hail netting, Victoria

The average orchard in Victoria was profitable to hail net, even in the absence of any damaging hailstorms. The minimum EAR from hail netting was \$450 per hectare, with an IRR of 9.9% and a payback period of 20 years. This increased to \$14,293 per hectare (IRR: 43.7%, Payback Period: 4 years) when 100% losses were incurred per annum. Victoria had a relatively high proportion of Pink Lady apples, which are the highest value variety, and the lowest proportion of Delicious apple, the lowest value variety.

The low value Delicious apples were profitable to hail net when minimum annual loss was at least 8 per cent of first grade apples. With no damaging hailstorms, the equivalent annual loss was \$1,150 per annum.

Fuji apples, too, were not profitable to hail net under low loss scenarios due to their relatively low price (Table 15, assuming all fruit were sold in Victoria) and packout combination. Minimum annual losses of 15% were required for hail netting of Fuji apples to be profitable in Victoria. With no damaging hailstorms, the equivalent annual loss was almost \$2,000 per annum.

Granny Smith, Gala and Pink Lady apples in Victoria were all profitable to hail net, irrespective of any hailstorm effects. The minimum EAR from hail netting Granny Smith apples was \$469 per hectare, with an IRR of 10% and a payback period of 19 years. Gala and Pink Lady apples were significantly more profitable to hail net, with EARs of \$2,755 per hectare and \$3,842 per hectare, respectively, when there were no losses to hailstorms.

The large difference between the profitability of Granny Smith apples and the other two varieties at higher levels of annual loss is the price effect (refer to 'Factors Affecting Profitability', p39).

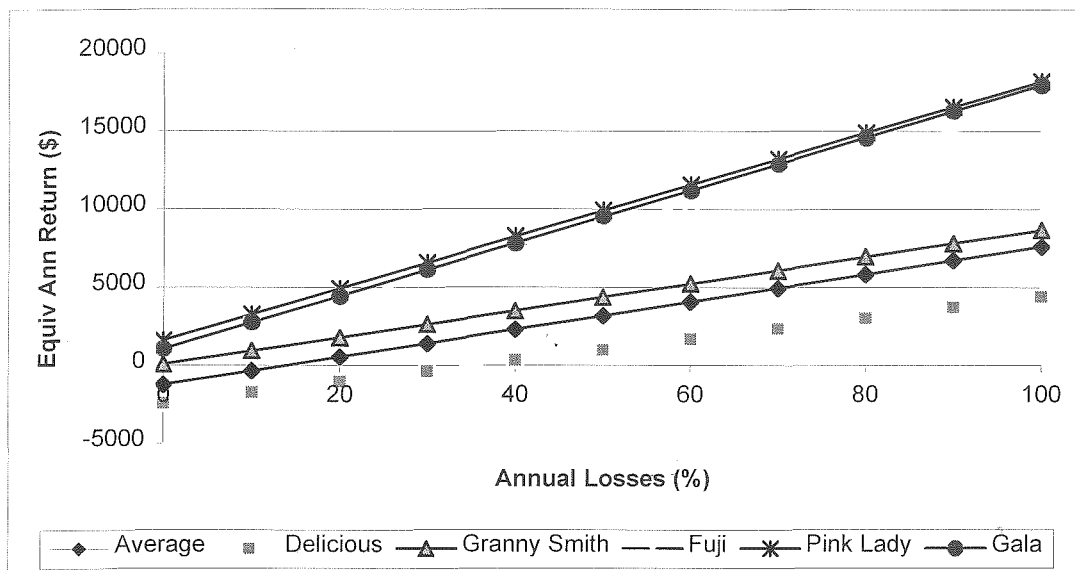


Figure 9. Profitability of hail netting, Queensland

In Queensland, the average orchard was profitable to hail net when minimum annual losses were at least 15% of first grade apples. This result was influenced by the relatively low value Delicious and Granny Smith apples (Table 15), which together accounted for a high proportion of the apples grown in Queensland (ABARE 1998).

Queensland Delicious apples were the lowest priced apples of all those analysed (Table 15). A minimum annual loss of 36% of first grade apples was required for hail netting to be profitable. With no damaging hailstorms, the EAR was almost -\$2,000 per hectare. This result was based on an average composite price for ordinary Delicious and Red Delicious combined. If Red Delicious prices alone were used in the analysis, the higher prices received for Red Delicious would increase the EAR above the -\$2,000 per hectare figure calculated for the two Delicious types combined.

Granny Smith, Fuji, Gala and Pink Lady apples were all profitable to hail net in Queensland, irrespective of any hailstorm effects. However, with no annual losses to hailstorms, the EAR of hail netting Granny Smith apples was just \$67 per hectare, with an IRR of 8.3% and a payback period of 24 years. Fuji, Gala and Pink Lady apples had minimum EARs of hail netting of \$1,000, \$1,065 and \$1,604 per hectare, respectively. This difference stems from the price difference between Granny Smith and the other varieties.

Factors affecting profitability

Unless otherwise specified, the results in this section were based on deterministic analyses using the following base case scenario:

- Total Cost of Hail Netting: \$25,000/hectare;
- Yield: 2000 cases per hectare plus 5% under netting;
- Packout: 75% without netting, 90% with netting; and
- Price: \$22.00 per case for first grade, \$150 per tonne for processing apples.

This scenario yielded the following results:

- EAR with no damaging hailstorms (annual loss is 0%) was -\$516 per hectare;
- 5% annual loss of 1st grade fruit was required for hail netting to be profitable; and
- EAR at 100% loss of first grade fruit was \$11,263, with an IRR of 38.4% and a payback period of 4 years.

Due to space limitations, only data showing the effect of changes in packout is presented in this report. The other analyses (effect of yield, apple price and hail netting cost on the profitability of hail netting) are presented in detail by Whitaker and Middleton (1999).

The profitability of hail netting increases with increasing packout. This effect is most noticeable under higher levels of annual loss to hailstorms (Figure 10). With no losses to hailstorms, less than \$80 separates the EARs of the two scenarios where the difference in packouts is 10% (65/75 and 75/85). When the annual losses to hail reach 100% however, the difference is almost \$1,650 per hectare. This also applies when the difference in packouts is 20% (65/85 and 75/95).

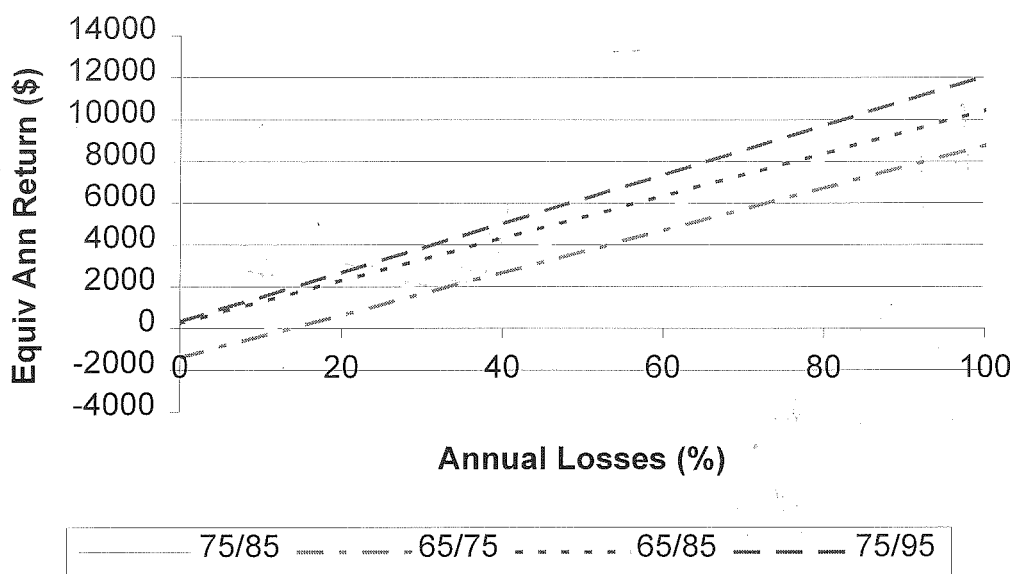


Figure 10. Effect of packout on profitability

A large increase in packout under netting relative to the packout achieved without hail netting had a greater influence on profitability. For example, compare the 65/85 scenario with the 75/85 scenario in Figure 10. While the 65/85 scenario (with a difference of 20%) has a low packout without hail netting, it is profitable irrespective of annual loss to hailstorms. The 75/85 scenario (with a difference of just 10%) requires at least 12% annual loss to hailstorms to be profitable. At 100% annual loss however, there is no difference in EAR.

To sum up the effect of the packouts on hail netting profitability:

- At low levels of annual loss, the difference in packout with and without hail netting is most influential.
- At high levels of annual loss, it is the packout under hail netting that is most influential.

The profitability of hail netting increases with increasing price of apples, especially at higher levels of annual loss to hailstorms (Whitaker and Middleton 1999). For the base case scenario described on p39, at a price of \$22 per case, 5% annual losses to hailstorms were required for hail netting to be profitable. With a low price of \$18 per case, however, the minimum annual loss required increased to 20% of first grade apples. With a high price (over \$24 per case) however, no losses to hail were necessary for hail net to be profitable (Whitaker and Middleton 1999).

Hail simulations – Granite Belt, Qld

The probabilities provided by individual growers were used to produce a probability distribution of hail events for the Granite Belt region, as shown in Figure 11.

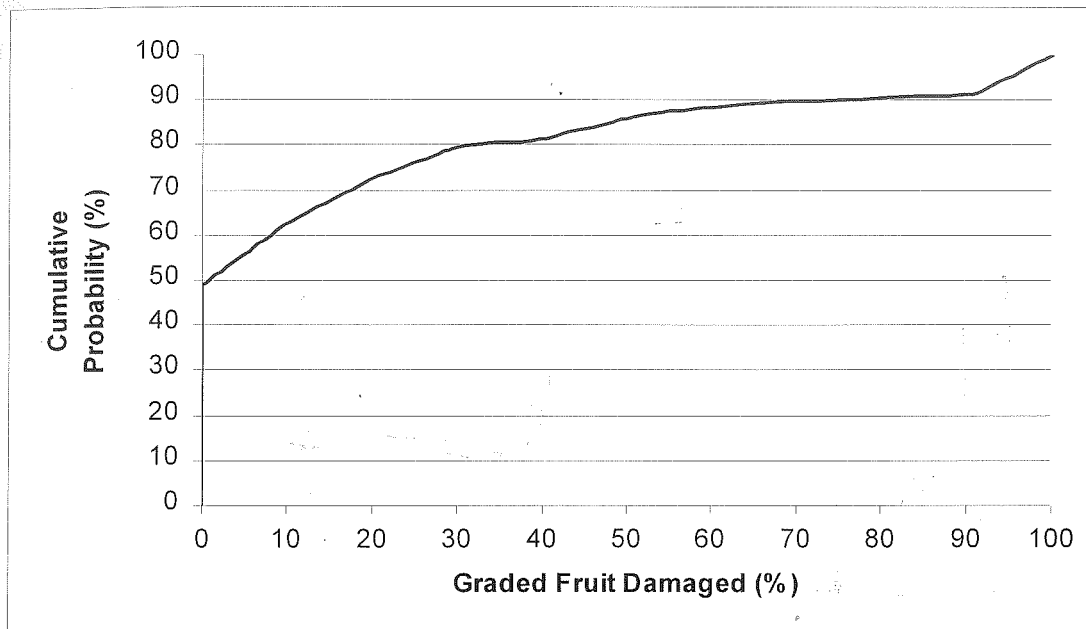


Figure 11. Hail event probability distribution

For any particular year, the probability of either no hailstorm or no damaging hailstorms was just under 50% (Figure 11).. This was a little higher than expected given that, on average, two hailstorms per year occur on the Granite Belt. The next most likely hail event was one which damaged 1–10% of the 1st grade apples, followed by an event that damaged 91–100% of the 1st grade apples. The expected annual loss was 19% of 1st grade apples.

Using simulations based on the above probability distribution for hail events, hail netting was profitable for all apple varieties, with the exception of Delicious apples (Table 16).

Table 16. Expected profitability of hail netting on the Granite Belt, by variety

Variety	Average Price (\$/case)	Packout (% without net / % with net)	Expected Equivalent Annual Return (\$/ha)	Expected IRR (%)	Expected Payback Period (years)
Average	18.59	78/94	355	10.2	14
Red Delicious	16.02	85/95	-1172	na	na
Granny Smith	19.32	70/95	1621	14.4	10
Fuji	28.51	65/80	3817	20.7	7
Pink Lady	31.26	60/75	4570	24.7	5
Royal Gala	28.53	70/85	4125	21.0	8

For the average apple orchard on the Granite Belt, the expected EAR of hail netting was estimated at \$355 per hectare, with an IRR of 10.2% and a discounted payback period of 14 years. There was a 30% chance of a negative EAR and a 50% chance of achieving an EAR of \$285 per hectare or higher.

With an expected EAR of -\$1,172 per hectare, hail netting of Delicious apples was not profitable. Given the relatively high packout under hail netting, this result reflects the low price of Delicious apples (Qld) on which the analyses were based (Table 15). The EAR ranged from -\$2,240 to \$612 per hectare, but there was less than 5% chance of achieving a positive result.

With high packout and average price, the expected EAR of hail netting Granny Smith apples was \$1,621 per hectare, with an IRR of 14.4% and a payback period of 10 years. The results for Granny Smith apples reflect the expected large increase in packout under hail netting. The EAR ranged from \$155 to \$4,227 per hectare.

Fuji, Pink Lady and Gala apples were all very profitable to hail net due to their relatively high prices. The expected profitability of hail netting Fuji, Gala and Pink Lady apples was \$3,817 per hectare, \$4,125 per hectare and \$4,570 per hectare, respectively.

Although the analyses suggest that the hail netting of Delicious is less profitable than other varieties, this conclusion is based on many assumptions that may or may not hold for a particular orchard or block of trees. The analyses show that the market price for apples was the most influential factor affecting the profitability of hail netting, and that even with a low incidence of hailstorms, an increase in returns of \$2 per case may make hail netting of Red Delicious a sound proposition. The market prices for Ordinary Delicious and Red Delicious were bulked for the Qld analyses, and growers would tend to concentrate on erecting hail net over their more profitable, higher value Red Delicious blocks, rather than over lower value Ordinary Delicious trees.

The probability distributions of likely hail events on the Granite Belt ranged from 0-100% (Figure 11). Severe hailstorms not only damage the current crop but can cause structural and bud damage to trees that may reduce or wipe out the apple crop for the subsequent 2 or 3 seasons. One such storm affected parts of the Granite Belt in late October 1999, and depending on damage to the trees, the crop loss may be as high as 200-300%. This scenario may make the hail netting of even the lowest price varieties a consideration, as well as prompting growers to consider attaching a dollar value to 'peace of mind' and having a good night's sleep.

Taxation depreciation of hail netting was excluded from the analysis, and if included, would make hail netting more profitable than the analyses suggest. The conclusions from the economic analyses are summarised in the recommendations (p45-46).

TECHNOLOGY TRANSFER

Publications and seminar presentations

- Middleton, S.G. (1996). Hail Netting of High Density Systems, Perry's Orchard. High Density and Dwarfing Rootstocks Field Day, NSW Agriculture 1996 Biennial Summer Field Day, Orange, NSW. 2 February 1996. 4 pp.

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- These publications were written in conjunction with oral seminar/workshop presentations. Details of the seminar dates & locations are provided in the list above.

RECOMMENDATIONS

Bee activity and pollination

To ensure adequate cross-pollination and fruit set of apple trees under hail netting, the following key points in the management of bees must be considered:

- Weak hives contribute nothing to the pollination of the crop.
- Adequate space between the top of the trees and the hail net is essential for optimum bee flight. Where there is little or no gap between the tree top and the net, bees are unable to fly freely and an uneven distribution of bees may occur in the block.
- Bees naturally tend to work along tree rows, however the more protected environment under netting as compared to uncovered trees can encourage increased bee foraging across alleyways and between adjacent tree rows.
- It is essential to place hives under hail netting to achieve good pollination. It is advisable to distribute hives throughout the netted orchard.
- Bees must be introduced under hail netting once flowering has commenced, usually about 3-5% bloom. Introduction of hives before this will only encourage bees to seek alternative nectar and pollen sources outside the netted area.
- Temporary removal of netting, or sections of it, during flowering is one means of assisting pollination. Bees are able to fly upward out of the hail net environment and then fly back down to the target trees.
- The disorientation and entrapment of bees in hail netting can be minimised by ensuring that tree tops do not grow close to the height of the hail netting, and/or by temporary removal of sections of hail netting during the blossom period.

Apple tree response to hail netting

- It is tree vigour that determines how apple trees respond to netting, and hence the yield and fruit quality under net.
- Although hail netting reduces sunlight levels by up to 25%, apple tree canopies may reduce sunlight levels by up to 95% or more.
- Heavy cloud cover, the decline in solar altitude and azimuth between midsummer and autumn, and the apple tree canopy itself can all rapidly deplete incident sunlight to levels that severely impact on potential orchard productivity, most especially when trees are excessively vigorous. It is in these circumstances that the 12-27% light reductions by hail netting are sufficient to reduce yields and fruit quality through both a direct effect on light levels, and an indirect effect of excessive vegetative growth in response to winter pruning and shade levels.
- Reduced fruit sunburn and russet, improved fruit colour and skin finish, and the elimination of bird damage are all benefits of hail netting that may make it an economic proposition in districts where the incidence of hailstorms is low.
- High yielding intensive hdp (high density production) systems on dwarfing rootstock are particularly suited to protection by hail netting, with high yields of fruit produced in well-illuminated exposed regions of the tree canopy which would otherwise be prone to sunburn without the presence of netting.

Tree management under hail netting

Orchards protected by hail netting need to rapidly attain and maintain high yields and packouts to recoup the cost of the netting and support structure. Hail netting makes it essential to produce the highest possible yields of premium quality fruit whilst minimising production costs, and it is only with control of tree vigour and attention to pruning and crop load that this can be achieved.

The tree management trials (pruning x crop load) under hail netting emphasise the important inter-relationship between crop load, pruning, shoot growth, yield and fruit size. Key points and recommendations to come from this work include:

- The management of trees under hail netting must aim to control tree vigour and maintain good light distribution throughout the canopy.
- Fruit size on vigorous trees under hail netting is reduced if inappropriate pruning strategies are used which encourage excessive shoot growth. The growth, yield and fruit size response of trees to all pruning treatments was affected by crop load.
- Heavy chunk winter pruning, whether done over one or two years, cannot be recommended as a pruning strategy for overvigorous trees under hail net, as it encouraged excessive regrowth which in turn reduced yields in subsequent years and set the trees into a biennial bearing pattern.
- 0 pruning in one year followed in the next year by light dormant pruning and/or summer pruning, effectively slowed tree growth down. High crop loads reduced regrowth, but also reduced average fruit size.
- It is essential to consider the response of trees to hail net in terms of their crop load and the pruning strategy used. The results from this project show that the pruning x crop load interaction determines how tree growth and productivity responds to the hail netted environment.
- A pruning x crop load strategy for vigorous trees under hail netting should aim for a balance between tree vigour (ideally <150 metres shoot growth annually; all shoots <75cm), crop load, fruit size and biennial bearing (0 or slight). On mature 15 year old Hi Early Red Delicious trees in Qld and NSW this was achieved with a crop load of 400-500 fruit/tree (3.0-3.5 apples/cm² TCSA) and a pruning strategy of 0 or light winter pruning, followed by light or chunk summer pruning.

Economic analyses

- Cost-benefit analysis was used to calculate the profitability of hail netting in the apple producing regions of Qld, NSW and Victoria. Criteria used were the Equivalent Annual Return (the annualised Net Present Value), the Internal Rate of Return and the Payback Period. The incidence and severity of hailstorms can vary significantly between growers within a district, therefore the cost-benefit analysis was developed in such a way that it can be used as a decision tool for individual growers. By entering information about his or her own orchard, a grower can determine if it is likely to be profitable to erect a hail net (Appendix II).
- In NSW, hail netting is profitable for each of the high value varieties (Fuji, Pink Lady and Gala) irrespective of any hailstorm effects. Granny Smith apples require only minimal losses to hailstorms to be profitable. However, New South Wales 'Average' and Delicious apples required annual losses of 13% and 27%, respectively to achieve positive returns from hail netting.
- In Victoria, hail netting is profitable for the 'Average', Granny Smith, Pink Lady and Gala apples, irrespective of any hailstorm effects. Again, Delicious apples were not profitable to hail net unless the minimum annual loss to hailstorms was 8%. Fuji apples, with a low packout and low price relative to other states, required minimum annual losses to hailstorms of 15%.

- Given the probability distribution of hail events estimated in this paper, hail netting on the Granite Belt, Queensland, was profitable for most of the apple varieties analysed. This was especially so for the higher value varieties (Fuji, Pink Lady and Royal Gala) and where packout under hail netting was high relative to the packout with no hail netting (Granny Smith). For these four varieties hail netting was profitable even with minimal or no losses from hailstorms.
- The analyses showed that the profitability of hail netting increases with decreasing cost of hail netting and increasing yield, packout and price. Of these, price was the most influential factor determining the profitability of hail net.

Further research

Project AP96014 has significantly expanded the available pool of knowledge on the effects of hail netting on apple tree growth and productivity, and the appropriate management of trees under hail net. In completing this project, four particular areas for further research have been identified:

Chemical thinning

- Evaluate the efficacy of spray thinning treatments under hail netting as compared with uncovered trees, and reconsider spray thinning recommendations for netted trees. This is of particular relevance given the observed better response to chemical thinning under net and the need to ensure overthinning of the high value apple varieties grown under hail netting does not occur.

Tree physiology

- Reasons for particular tree responses to pruning, crop load manipulation etc presented in this report are hypotheses until they can be tested and explored further in tree physiological studies. Such studies need to consider source/sink relationships and dry matter partitioning in the tree, and include measures of photosynthesis and transpiration. It is only with a complete understanding of tree physiological responses to hail net that tree management will be able to fully exploit the netted environment.

Irrigation

- The inter-relationship of pruning, crop load, shoot growth, yield and fruit size has been demonstrated in this project. Water relations are obviously a critical part of this. With less evapotranspiration, improved tree water use efficiency and lower water use should be possible under net, with consequent productivity, financial and environmental benefits. Appropriate irrigation strategies under net need to be determined, with particular emphasis on reduced water use and irrigation timings that minimise shoot growth and maximise yield and fruit quality.

Orchard system trials

- Development of hdp systems (tree training x planting density x rootstock) specifically tailored and adapted to maximising apple orchard productivity under hail netting. Apples under netting can be borne in more exposed, well-illuminated positions in the tree canopy than is possible without net. This permits the development of highly productive hdp systems producing economic crops within two years of planting, using precocious dwarf rootstocks that could otherwise not be considered without the protection from sunburn that hail netting offers.

Industry/commercial activities

- The project and its outcomes have generated considerable interest, not only from the pomefruit industry but also from the broader horticultural industry and from the general community.
- The project outcomes have been, and continue to be, adopted by industry as a consequence of regular workshops, seminars and extension publications (refer to Technology Transfer).
- The establishment and success of a Granite Belt company specialising in the design and construction of hail netting structures has further assisted in the adoption of project outcomes by industry. The success of this company has also facilitated the rapid expansion of hail netting into areas where the incidence of hailstorms is relatively low, and where net is often being erected for primary reasons other than protection from hail.
- The interest in hail netting of horticultural crops, and the level of enquiries received from interstate and overseas regarding our work indicates that the project and its outcomes are widely known.

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APPENDIX I. FRUIT COLOUR CLASSES



Plate 1. Rating classes (1-5) used to visually assess the colour of Hi Early apples. The colour variation between the apples in this photo can occur within a single tree.

APPENDIX II. SAMPLE SPREADSHEET FOR APPLE HAIL NET BENEFIT COST ANALYSIS.

Decision tool

Given the variability in hailstorm incidence and severity, not just within the Granite Belt region, but for most apple growing regions of Australia, as well as the variability in management practices, prices and yields, an 'average' analysis is not always useful to the individual grower. Hence, the spreadsheet this analysis uses was set up to allow a high level of flexibility.

The following page is the main input screen. Data that can be changed include:

- life expectancy of the net and structure, with restrictions on the minimum years;
- total cost of hail netting and the breakdown of this cost;
- salvage values of net and structure;
- annual maintenance cost of hail netting, including an allowance for annual rolling and unrolling (which is not practiced on the Granite Belt);
- annual insurance cost for netting;
- apple variety and life expectancy of tree;
- yield by year and yield increase under netting;
- price by grade of apple – the program allows for up to four grades;
- packout percentage for each grade of apple;
- orchard operation costs and other production costs – with an option of using a gross margin template to calculate these costs;
- probabilities for each possible hail event, with the option of doing a deterministic analysis; and
- discount rate.

APPLE HAIL NET BENEFIT COST ANALYSIS - Main Page

Details of the netting:

Notes: Enter data only in yellow cells. Green cells contain formulas.

Life Expectancy:

Netting	12	years	(minimum of 8 years)
Structure	40	years	(minimum of 25 years)
Total Cost:	25000	\$/ha	

Cost Breakdown:

	% of Total Cost	Calculated Cost
Netting material	50.0 %	12500 \$/ha
Structure Material	20.0 %	5000 \$/ha
Netting Labour	4.5 %	1125 \$/ha
Structure Labour	25.5 %	6375 \$/ha
Must Sum to 100	100.0	25000

Salvage Values at end of life expectancy:

Netting material	1250	\$/ha
Structure Material	500	\$/ha

Annual Costs:

Structure Maintenance	200	\$/ha per annum
Net Maintenance		\$/ha per annum
Retensioning	200	\$/ha per annum
Roll/Unroll		\$/ha per annum

	% of Total Cost	Calculated Cost
Annual Insurance:	2.0 %	500 \$/ha per annum

Details of the apple trees:

Apple Variety:	All Varieties
Age of trees when net first established:	2 years
Life of tree (total years in ground):	15 years

Yield (no hail net & no hail):

Year	Low	Average	High	
1	0	0	0	cases/ha
2	100	100	100	cases/ha
3	500	500	500	cases/ha
4	1250	1250	1250	cases/ha
5	2000	2000	2000	cases/ha

	Low	Average	High	
Export	20.00	20.00	20.00	\$/case
1st Grade	10.43	19.88	30.37	\$/case
2nd Grade	20.00	20.00	20.00	\$/case
Processing	90.00	150.00	200.00	\$/tonne

Yield Increase Under Netting (optional): 5 %

Volume of Standard Case: 19 kg

Packout:

	without hail net	with hail net	%
Export	0	0	%
1st Grade	77	93	%
2nd Grade	0	0	%
Process	23	7	%
	100	100	

The differences in packouts should only reflect the secondary effects of the hail net (eg reduced sunburn). Do not include any consideration for packout lost due to hail storms. Packout must sum to 100

Orchard Operation Costs:

Without Hail Net	4202	\$/ha
With Hail Net	4160	\$/ha

Other Production Costs:

Graded Fruit	9.96	\$/case
Processing Fruit	86.28	\$/tonne

Details of hailstorms:

Probabilities:

Hail Storm	Probability (%)	Cumulative (%)
No Hail Storm/No Damage	49.0	49
Hail Storm: 1 - 10% Damage	13.7	63
Hail Storm: 11 - 20% Damage	9.8	73
Hail Storm: 21 - 30% Damage	7.0	80
Hail Storm: 31 - 40% Damage	1.7	81
Hail Storm: 41 - 50% Damage	4.6	86
Hail Storm: 51 - 60% Damage	2.8	89
Hail Storm: 61 - 70% Damage	0.8	90
Hail Storm: 71 - 80% Damage	0.8	90
Hail Storm: 81 - 90% Damage	0.0	90
Hail Storm: 91 - 100% Damage	9.6	100
Must sum to 100	100	

OR: Average Annual Loss of Graded Fruit:
Loss: %

Discount Rate:

Discount Rate: 8 %

Summary

Apple Variety:	Sensitivity
Net Establishment Cost:	25000 \$/ha
Expected Steady State Yield:	2100 cases/ha (under net)
Expected Annual Loss:	18.8 % of graded fruit
Expected	
Equivalent Annual Return:	2303 \$/ha (Exp NPV= 24247 \$/ha)
IRR:	19.7 %
Payback Period:	7 years

