Hail Netting To Increase Apple Orchard Productivity

Final Report

PROJECT AP320

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SUMMARY

A severe hailstorm can destroy an apple crop in minutes, and in the hail-prone regions of Australia increasing areas of apple trees are now protected with hail netting.

Trials conducted on commercial apple orchards in Queensland (Stanthorpe), New South Wales (Orange) and Victoria (Drouin) have measured the effect of hail netting on orchard climate, and how trees respond (growth, yield, fruit quality) to the unique environment beneath netting. Changes in pruning, irrigation, thinning and other management practices are required to maximise the productivity of netted orchards, and this is being investigated in current trials (Project AP614, "Maximising apple orchard productivity under hail netting").

Simultaneous measurements from automatic weather stations set up within adjacent blocks of apple trees under and outside hail netting, show that light levels (photosynthetically active radiation) are reduced by 20 to 25% beneath black net, by 18% beneath grey net, and by 12 to 15% under white netting. These levels are significant, but manageable. Other climatic effects of hail netting include increases in humidity of up to 10%, and reductions in windspeed by 50% or more.

Hail net has little effect on air, grass or soil temperature, except on warm to hot days when air temperature may be reduced by 1 to 3°C. Perceived cooler temperatures under netting are due to reduced radiation. Hail net offers no frost protection.

It is the tree responses to the environmental effects of hail netting and the management of trees under net that are of most practical significance. Improved skin finish, reduced sunburn and reduced windrub on fruit are obvious benefits of hail netting, but there are more important effects that have greater implications for tree management.

Tree response to hail netting is largely determined by vigour. Netting most noticeably affects tree growth, yield, fruit size and colour on vigorous trees that would have shading problems even without artificial protection. Reduced fruit size and increased shoot growth occurred on vigorous trees under black net at Orange, NSW (Hi Early Delicious) and Drouin, Vic (Granny Smith). Conversely, fruit size was maintained or slightly increased on semidwarf trees (Royal Gala, Red Fuji) under hail netting at Stanthorpe Qld, with no effect of net on shoot growth.

At all trial sites, fruit set was lower on trees under net, with fewer multiple fruit clusters. Fruit set reductions are not large but are beneficial, with less follow-up hand thinning required on trees under net. There is scope to use the shading effects of hail netting to encourage self-regulating trees that are not biennial bearing and require minimal thinning, and this is now being investigated as part of project AP614.

Hail net can affect fruit colour, but this will depend on tree vigour and fruit position in the canopy. The colour intensity of Hi Early apples on trees under black netting at Orange has been slightly better than on fruit from uncovered trees. Due to internal shading effects on fruit set, a higher proportion of fruit under black net occurred in 'well-lit' parts of the tree where colour development was not adversely affected.

Although hail net reduces light levels by 15 to 25%, the leaf canopy and structure of the trees themselves can reduce light levels by up to 95%, regardless of the presence of netting. Daily weather conditions (cloud cover) and the time of year (solar altitude and azimuth) also significantly affect the light levels incident on trees. Hence, large shading effects in the tree are not primarily due to the hail netting itself, although on vigorous trees netting may contribute to excessive shoot growth and classic 'shading response' symptoms, such as larger leaves.

Dormant pruning opens up the tree to more light, but cuts on vigorous trees under hail net must be minimised to restrict regrowth. Mistakes in tree pruning are exacerbated on vigorous trees under netting, with shoot growth (shoot numbers and shoot length) greater than on comparable uncovered trees. Tree vigour control under hail net is essential.

By changing the orchard climate, hail netting not only affects the trees but also the foraging behaviour of bees. Observations under "fixed net" structures on the Granite Belt, Qld showed that fewer bees were working on trees under black netting than on uncovered trees. Bee behaviour is complex and their efficacy in tree pollination is influenced by floral stage (tree "attractiveness" to bees), time of day and weather conditions. This has implications in the siting of hives and polleniser varieties, and requires further investigation.

The management of trees under hail netting needs to consider pruning (both dormant and summer), irrigation, crop load, thinning and pollination/bees. Hail netting is a large investment and it is essential to use the shading effects of net to advantage to encourage self-regulating trees that produce high quality fruit. Pruning, irrigation and crop load/thinning strategies for apple production under hail netting are currently being investigated (Project AP614 "Maximising apple orchard productivity under hail netting") and aim to control the vigour of trees under netting, maintain good light distribution throughout the tree canopies and maximise fruit yield, size and quality.

INTRODUCTION

The high incidence of hail in many apple producing districts of Australia has seen increasing numbers of orchardists look to options such as hail net for the protection of fruit. Hailstorms in several states in recent years have again shown the vulnerability of the Australian apple industry to hail damage. Domestic and export markets demand the consistent supply of high quality, unblemished fruit, and the use of hail netting for fruit protection gives hail-prone apple production regions the ability to satisfy the fruit quality and volume expectations of markets.

Covering orchards with hail netting artificially creates a new environment for apple production, most obviously characterised by lower light levels than are incident on uncovered trees. Internal tree shading reduces yield, fruit size, colour and total soluble solids (Jackson and Palmer 1977; Doud and Ferree 1980), but it is not known whether these shading effects also occur beneath hail netting under Australian conditions.

Giulivo (1979) monitored the climate of hail-netted orchards in northern Italy, but these measurements are inappropriate to Australian orchards, which experience higher light intensities and solar angles of incidence by virtue of their closer proximity to the equator. Scott (1989) and Campbell (1991) have done limited *ad hoc* climatic measures beneath hail net in Australia, but the environment within apple tree canopies, the effects on tree growth and productivity, and the appropriate management (pruning, thinning, irrigation) of trees for maximum productivity beneath hail netting were not considered.

The technology and adoption of hail netting is relatively recent, and the Australian apple industry is unique in that the necessity for hail protection is high relative to most other apple producing countries. It is likely that hail net confers substantial advantages for orchard productivity under the high light intensities experienced in Australia, that are as yet unknown. Existing management practices of tree training, pruning, planting density, thinning, irrigation etcetera are all based on current established practices where there is no net, and hence do not fully exploit the hail net microclimate.

This project consists of three distinct components:

1. Measure in detail the effect of hail netting on orchard microclimate.
2. Evaluate the growth, yield and fruit quality responses of apple trees to the unique environment beneath hail netting.
3. Tree management trials (pruning, thinning, crop load, irrigation, bee management) to maximise the yield and quality of fruit produced under net, and reduce orchard production costs to help offset the establishment costs of hail netting structures. This work is continuing as project AP614 “Maximising apple orchard productivity under hail netting”.

MATERIALS AND METHODS

(a) 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. Close-up photographs of the hail net at sites 1, 2, 3 and 4 are shown in Appendix I.

All orchards were managed according to standard commercial practices. Under-tree trickle irrigation systems were used to water trees as required, with the irrigation of orchards in Queensland scheduled according to neutron moisture meter readings. Weed-free herbicide strips were maintained beneath the tree rows, whilst the inter-row alleyways consisted of a regularly mown grass sward. Pest and disease control was based on orchard monitoring and Department of Agriculture spray and IPM recommendations. Proprietary fertilisers were applied to trees as necessary.

(b) Orchard climate

Climatic measurements were taken in commercial apple orchards within blocks of identical trees (date of planting, variety, rootstock, tree density, soil, tree management) where hail netting had been erected over part of the block, with the remainder left uncovered. Block size was a minimum of one hectare, but usually much larger. Plate 1 shows the trialsite at Orange, typical of all sites in the project.

Two automatic weather stations (AWS) were used simultaneously; one weather station within trees under the hail netting and the other weather station within uncovered trees. The weather station under net was located at least six rows from the outer perimeter of the net structure, and similarly the AWS outside net was at least six rows from the edge of the block (except at Drouin, Vic). Sites were selected to avoid local topographical effects on microclimate.

Each weather station was positioned within the tree row, midway between two trees (Plate 2). The automatic weather stations (Monitor Sensors, Caboolture, Queensland, Australia) were solar powered with gelcell batteries, and each unit consisted of a 16 channel data logger (model LL-128) with 224K memory, 4.5 watt solar panel, metal mast and Stevenson Screen sensor shelter. The data logger was configured to record the readings from each of the 16 channels every six minutes, 24 hours a day.

The 16 sensors used with each weather station were:

- 10 PAR (photosynthetically active radiation) cosine-corrected silicon cell radiation sensors, individually calibrated.
- 4 Air temperature sensors (± 0.1°C accuracy).
- Relative humidity (capacitance) sensor protected by a sintered bronze filter.
- Anemometer (3 cup).

An AWS set up under white net at site 3 on the Granite Belt, Qld, is shown in Plate 3. Weather stations were in position for at least a week at a time at each site, with measurements taken at regular intervals throughout the year. Stored data was downloaded on-site (Plate 4) and collated and analysed in the laboratory using standard software packages.

For each weather station, three lightmeters were positioned above the tree. In the case of trees under netting, these lightmeters were 50 cm below the hail netting. The remaining seven lightmeters were positioned within the tree canopy to encompass a range of light levels, with locations varying from exposed parts of the tree to shaded internal regions. The positioning of lightmeters within the canopy of the tree covered by net was always identical to the lightmeter positions within the tree outside the net.

Windspeed was measured at a height of 2 metres on the outer edge of the hedgerow, where the anemometer was unobstructed by foliage. Air temperature and relative humidity were measured inside a standard Stevenson Screen at 1.6 metre height within the row midway between two trees (Plates 2 and 4). Soil temperature (10 cm depth), grass temperature (alleyway) and air temperature (outside Stevenson screen) were also measured.

(c) Tree growth and productivity

Tree growth, fruit set, yield and fruit quality measurements were made on a minimum of 16 trees under and 16 trees outside net (Queensland and New South Wales sites) and on nine covered and nine uncovered trees at the Drouin site.

Annual shoot growth was measured after the cessation of shoot growth, by counting and recording the lengths of all extension shoots (current season growth) that arose above a height of two metres. Tree butt circumference was annually measured in winter, 15 cm above ground level, and measurements converted to trunk cross-sectional area (TCA).

Flower clusters were counted each spring 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 cm^2 TCA.

At harvest, all fruit from each datum tree was picked and assessed. Fruit were harvested and assessed within one metre height intervals above ground level, to account for effects of fruit location on quality. Particular care was taken to individually assess and record the quality of apples harvested in the vicinity of lightmeters within the tree canopy were located, so that fruit quality could be related to measured light levels.

Fruit from all trees were counted and weighed in bulk (within each one metre height interval), and the individual fruit circumferences measured on all fruit (NSW and Vic sites) to indicate the fruit size distribution. All apples from one tree under net and one tree outside the net were also weighed individually, to correlate fruit diameter with fruit weight. Where practicable, apples from the Queensland trial sites were graded with a computerised electronic weight size grader (PSF Equipment).

Fruit firmness and total soluble solids (TSS) were measured on a 100 fruit sample from one tree under net and one tree outside the net. These fruit were the apples harvested in the vicinity of lightmeters within the tree canopy, at standardised locations to account for any positional effects on fruit firmness and sugar content. 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 II for Gala. The sunburn ratings used for Granny Smith are also shown in Appendix II. As with yields and other fruit quality parameters, data on the skin finish and appearance of fruit was separately recorded for each one metre height interval.

(d) Tree management experiments

Preliminary experiments to determine the appropriate management of trees under hail netting commenced in project AP320, and have been considerably expanded in current project AP614. Three aspects of tree management considered were crop load, pruning, and bee activity under net.

(i) Crop Load

After fruit set counts in spring 1994 and spring 1995, trees were handthinned to standardise crop loads so that the effects of hail netting on fruit size could be determined. Three crop load treatments (heavy, medium and light) were compared, with four to eight single-tree replicates per treatment (depending on the site) for each of the netted and uncovered blocks.

Hand thinning treatments were applied on the basis of calculated crop load per cm^2 TCA (trunk cross-sectional area), and at Orange NSW in December 1994 this broadly corresponded to crop loads of 3.0 (light), 5.0 (medium) and 6.5 to 7.0 (heavy) fruit/cm^2 TCA.

The effect of crop load on yield, fruit size and return crop was measured to test the hypothesis that trees protected by hail netting may be capable of adequately sizing up a heavier crop than uncovered trees, with less tendency to biennial bearing.

(ii) Pruning

Based on results from the crop load experiments just described, a pruning trial commenced at the Orange site in 1995/96 and is continuing in expanded form in project AP614.

A preliminary trial was designed to investigate pruning strategies for apple trees protected by hail netting, following observations of excessive regrowth behind dormant pruning cuts made to vigorous trees under net (refer to Results).

In 1995/96 the trial consisted of four treatments, replicated three times under net and three times out in the open using single-tree plots:

- nil pruning (control)
- dormant pruning (chunk)
- dormant pruning (standard)
- summer pruning (chunk)

The dormant chunk pruning treatment concentrated on a few large pruning cuts to improve the tree structure and create a new framework with a well-defined central leader. The "standard" dormant pruning treatment did not attempt to alter the current tree framework, and consisted of many smaller cuts (120-160), few large cuts, and the maintenance of the existing tree structure. Summer pruning was done in February 1996 and was as described for the dormant chunk pruning treatment. That is, it could be considered as the dormant chunk pruning treatment, but done in summer after the cessation of annual shoot growth.

(iii) Bee activity

There is some concern, particularly with the "fixed-net" structures erected for hail protection in Queensland, that hail netting not only affects trees, but also the foraging behaviour of bees. In spring 1994 a small trial was designed at Site 3 in Queensland to monitor the activity of bees working apple trees protected with hail netting, and this work is continuing in project AP614.

Bee foraging behaviour was observed within immediately adjacent blocks of Gala apple trees that were covered by either (a) black hail netting, (b) white hail netting or (c) out in the open (uncovered).

Bee counts were made over a 30 second period on each of nine trees per 'net type', with four such counts made per tree per half hour time period between 9 am and 12 noon. The 30 second counts were done on trees in standardised order, then repeated in that same order. Counts under each of the three ' net types' were made simultaneously by three observers. A fourth person monitored return bee visits to the hives themselves. The position of the nine trees in relation to hives was also standardised, with three trees in adjacent rows at five metres, three at 25 metres and three at 50 metres along the row(s) from the nearest hives.

Table 1. Trial sites used to measure the effect of hail netting on orchard microclimate and apple tree growth and productivity.

	Site 1	Site 2	Site 3	Site 4	Site 5
Location	Orange, NSW	Drouin, Vic	Stanthorpe, Qld	Stanthorpe, Qld	Stanthorpe, Qld
Variety	Red Delicious (Hi Early)	Granny Smith	Red Fuji, Gala	Red Delicious (Hi Early), Royal Gala, Red Fuji, Granny Smith	Granny Smith
Rootstock	Northern Spy	Northern Spy	MM106	Merton 778 (Granny Smith), MM106 (other varieties)	Merton 793
Tree Age (1995)	12 yo	17 yo	3-6 yo	3-6 yo	10-15 yo
Tree Trunk Girth (cm)	35.0	51.2	20.0 - 28.0	15.0	34.0
Tree Spacing	5.0 x 2.8 m	5.0 x 3.0 m	5.0 x 2.5 m	3.5 x 1.25 m	5.6 x 4.4 m
Planting Density	710 trees ha^{-1}	666 trees ha^{-1}	800 trees ha^{-1}	2280 trees ha^{-1}	400 trees ha^{-1}
Tree Training	Central leader	Vase	Central leader	Central leader	Vase
Hail Net: **-Pitch** **-Colour**	Flat Black	Flat Black	Flat, Gable White, Black, Grey	Flat, Gable White, Black, Grey	Flat Black/White
	Appendix I	Appendix I	Appendix I	Appendix I	

Plate 1. Trial site at Orange, NSW. The trees are Hi Early Red Delicious on Northern Spy rootstock, planted in 1983 in north/south rows. This photo was taken in October 1995, when the hail net was still partially rolled up.

Plate 2. Trial site at Drouin, Vic. The automatic weather station is positioned within the tree row, midway between two Granny Smith trees. A temperature sensor in a miniscreen (far right) and a lightmeter are visible in the alleyway.

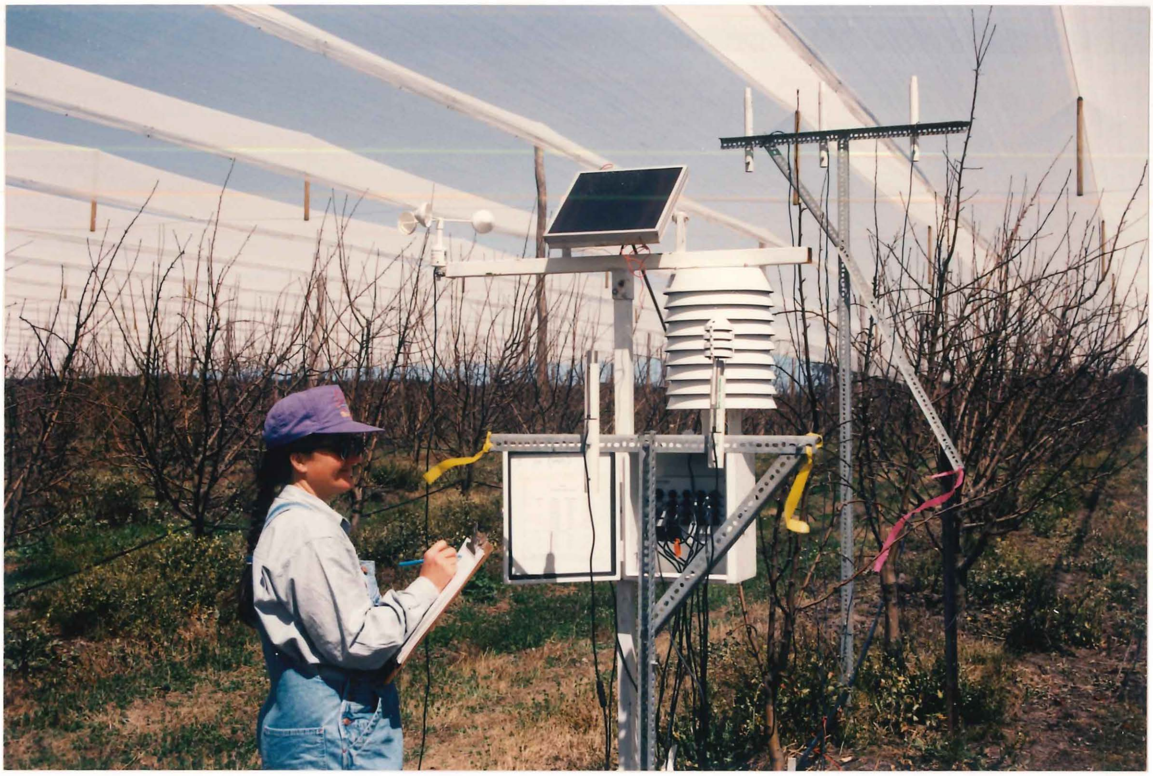


Plate 3. An automatic weather station under white hail netting on the Granite Belt, Qld. The data logger is housed in the white box; above this is a Stevenson screen that encloses a temperature sensor and a humidity sensor. Also visible are an anemometer, solar panel, two temperature sensors in the foreground (one in a small screen and one exposed), and three lightmeters above the dormant Red Fuji trees.

Plate 4. Simon Middleton downloads data from a weather station. Two lightmeters are visible on the right, within the canopy of a Red Fuji tree on MM106 rootstock.

RESULTS

(a) Orchard climate

The effect of hail netting on microclimate was similar in all orchards. Since considerable climatic data was generated from the five orchard sites, it is only practical to present a selection of data in this report. The results presented, however, are sufficient to illustrate the climatic trends measured at all orchard sites.

(i) Light

Incident light levels (photosynthetically active radiation or PAR - the wavelengths used by apple leaves in photosynthesis) were reduced by 20 to 25% beneath black net (Figures 1 to 5) and by 12 to 15% beneath white netting (Figure 1). On the Granite Belt, grey net reduced PAR by approximately 18% (data not shown). The results presented in Figures 1 to 5 were consistent at all sites, as illustrated in Appendix III for consecutive days at Site 2 (Drouin, Vic) and Site 3 on the Granite Belt, Qld.

In summer, close to the longest days of the year, the light levels on fine days in Victoria (Figure 2) are little different to those on the Granite Belt, Queensland (Figure 1). Cloud cover dramatically reduces light levels (compare Figures 2 and 3), and incident light levels are much lower late in the season (compare Figures 2 and 4). In mid-April, which coincides with the harvest of mid to late-season apple varieties, light levels on overcast, wet days are extremely low, regardless of the presence of netting (Figure 5).

(ii) Temperature

Hail net had little effect on air (Table 2), grass or soil temperatures (Appendix IV). On warm to hot days, air and soil temperatures under hail netting may be reduced by 1 to 3°C, as shown in Appendix IV (Tables 1 and 2). Early in the morning, there is little or no effect of netting on temperature (refer to minimum temperatures in Table 2, and minimum temperatures and 6 am temperatures in Appendix IV).

Air temperatures were measured "in the shade", inside a Stevenson screen as per Australian Bureau of Meteorology specifications. The screen excludes radiation and restricts wind, hence permitting a "true" measure of air temperature. Readings from a temperature sensor with its sensory tip exposed to radiation and wind were up to 4 to 6°C higher than measures made inside the screen (Table 4 in Appendix IV).

(iii) Relative humidity

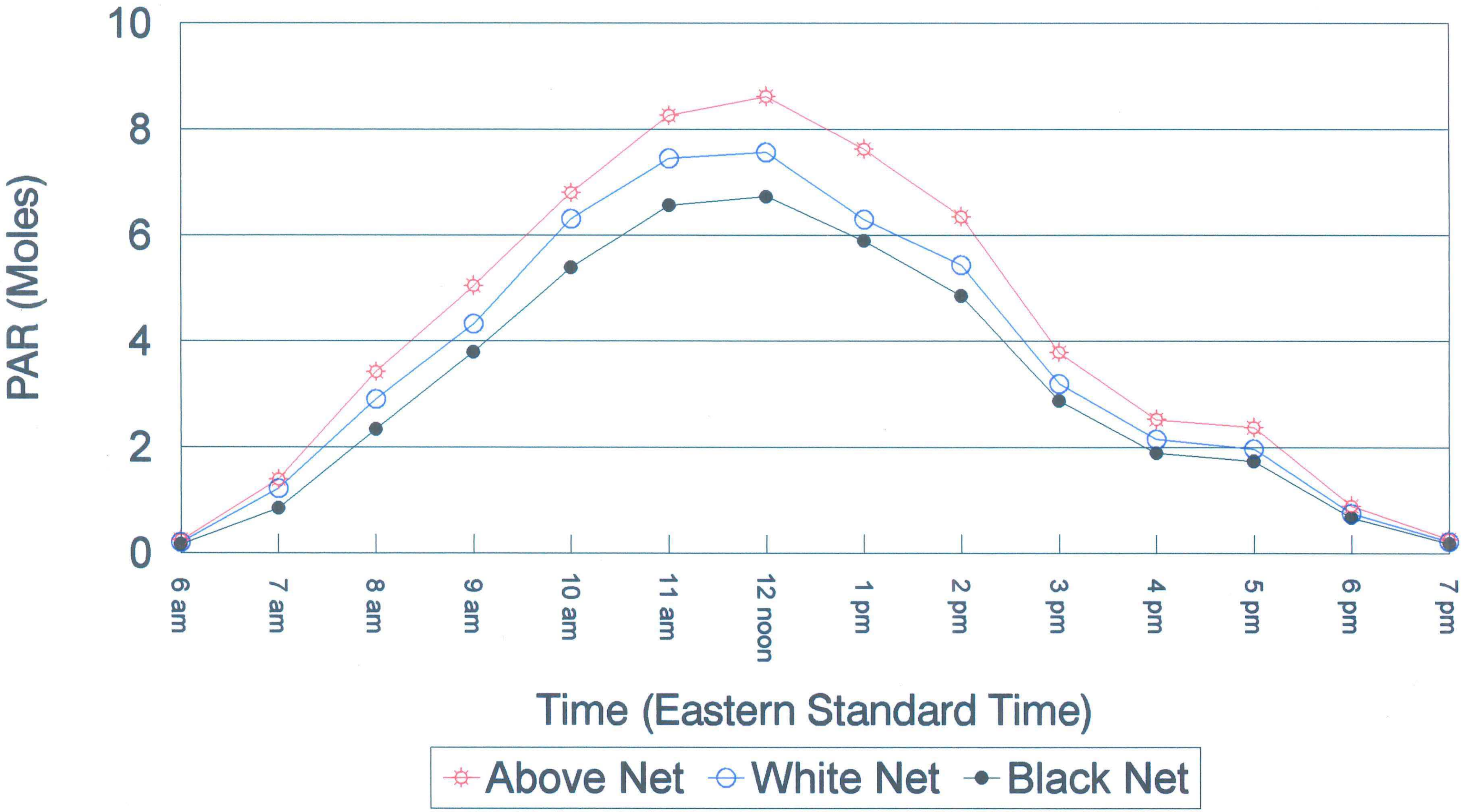
Under hail netting, humidity is consistently increased by up to 10% (Table 3) and at times by up to 15 to 20%. During rainfall the humidity both under and outside net is obviously at or close to 100%, however following rainfall the humidity under net remains high and takes longer to fall than it does within uncovered trees (Table 3, refer to 9 December 1994).

(iv) Wind

Hail net consistently reduces windspeed (windrun) by 50% or more (Figure 6). Maximum windgusts under net are also much lower than in the open (data not shown).

Figure 1. Light penetration (PAR) through hail netting

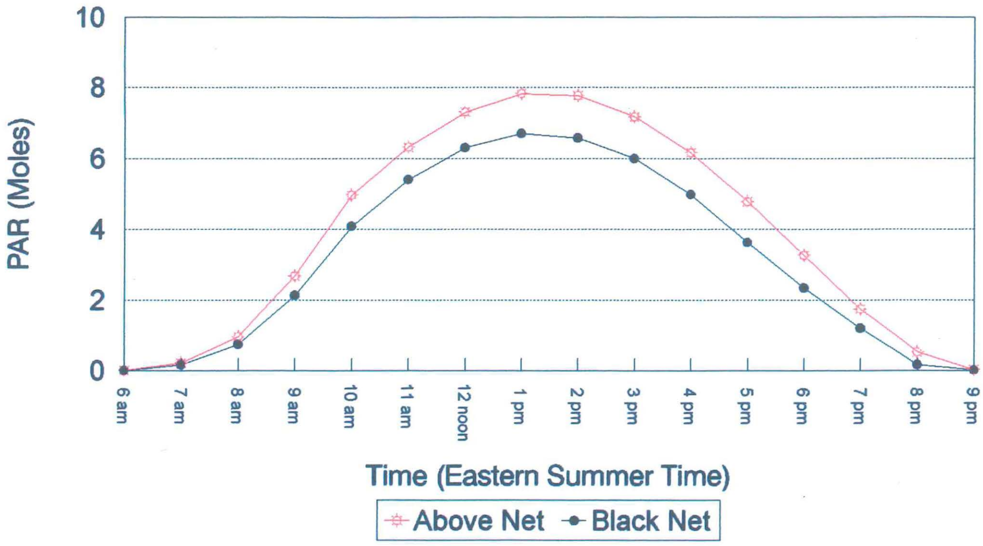
Granite Belt, QLD. - 15 January 1995 - Fine, clear



Diurnal light penetration (PAR) through the White net = 87.2%, Black net = 76.3%.

Figure 2. Light penetration (PAR) through hail netting

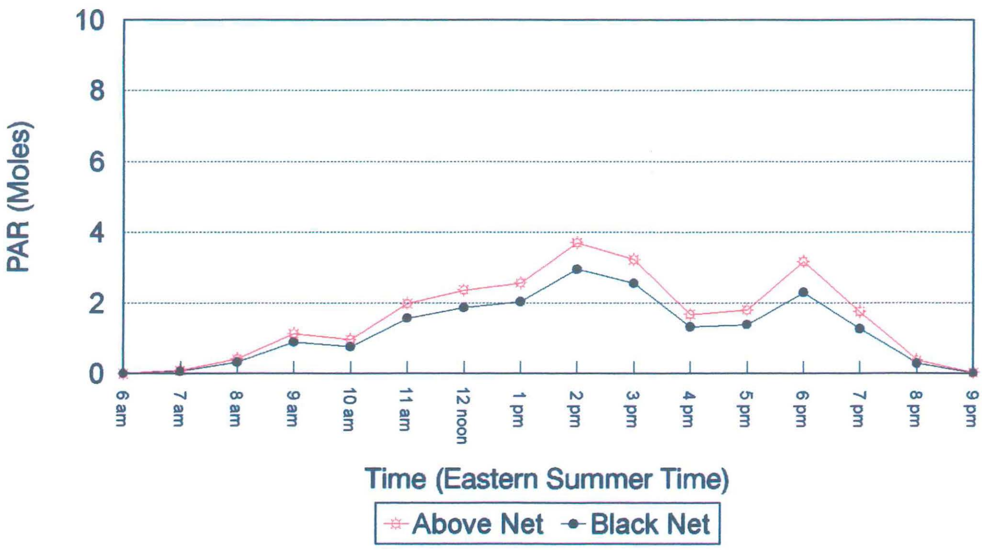
Drouin, VIC. - 27 November 1995 - Fine, 100% blue sky



Diurnal light penetration (PAR) through the Black net = 81.9%.

Figure 3. Light penetration (PAR) through hail netting

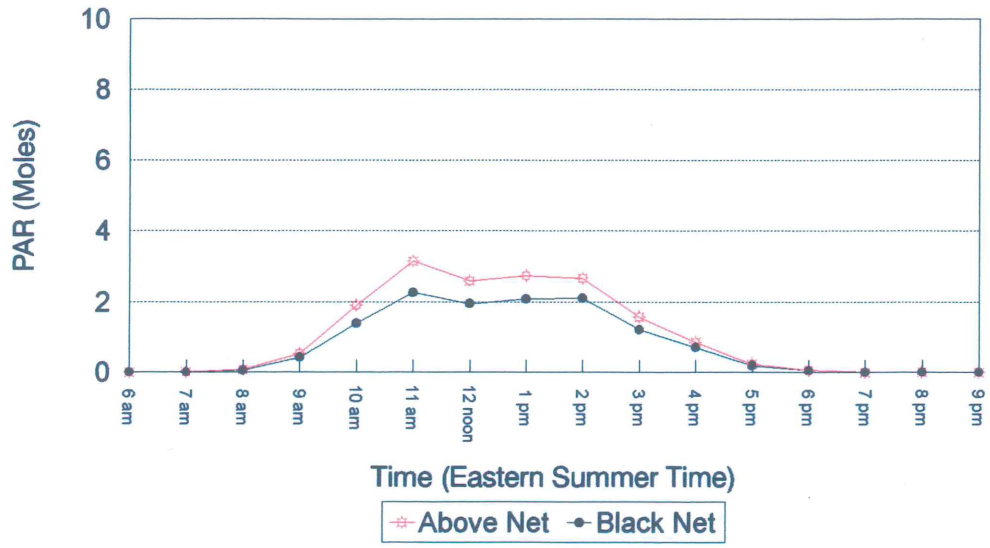
Drouin, VIC. - 29 November 1995 - Overcast, rain



Diurnal light penetration (PAR) through the Black net = 78.2%.

Figure 4. Light penetration (PAR) through hail netting

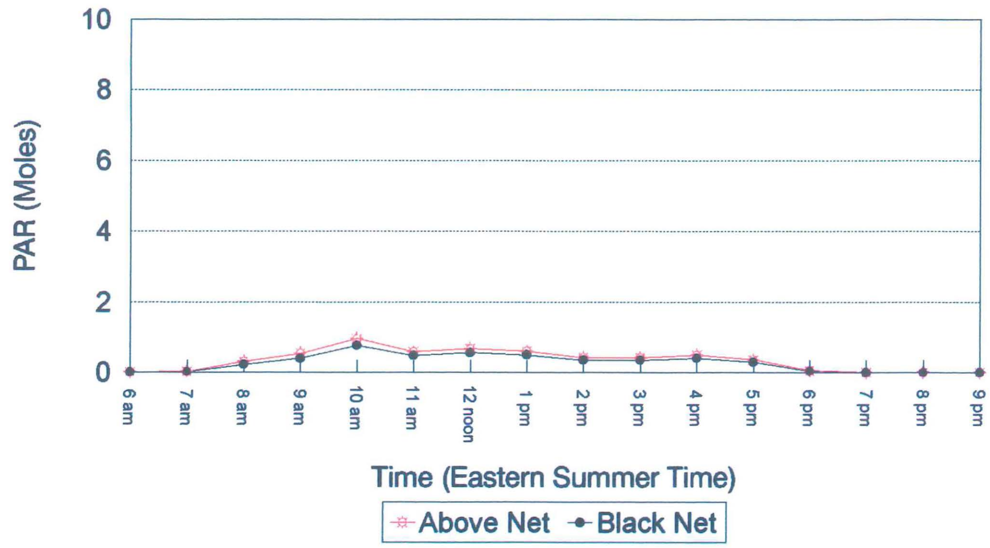
Drouin, VIC. - 16 April 1996 - Sunshine & cloud.



Diurnal light penetration (PAR) through the Black net = 76.1%.

Figure 5. Light penetration (PAR) through hail netting

Drouin, VIC. - 17 April 1996 - Dull, heavy rain.



Diurnal light penetration (PAR) through the Black net = 80.7%.

Table 2. Air temperatures (°C) - Drouin, Vic.

Air temperatures measured inside a Stevenson screen 160 cm above ground level within the tree row.

	MAXIMUM		MINIMUM		DAILY AVERAGE	
	Black Net	Open	Black Net	Open	Black Net	Open
27 Nov 1995	25.2	25.1	10.7	10.8	17.7	17.7
28 Nov 1995	23.3	23.4	11.7	11.8	16.2	16.2
29 Nov 1995	19.4	19.6	9.5	9.5	13.7	13.8
14 Apr 1996	15.0	15.1	8.8	8.7	11.8	11.9
15 Apr 1996	16.1	16.0	8.8	9.1	11.9	12.0
16 Apr 1996	13.9	13.9	7.6	7.6	10.5	10.6
17 Apr 1996	11.4	11.5	5.2	5.3	8.9	8.9

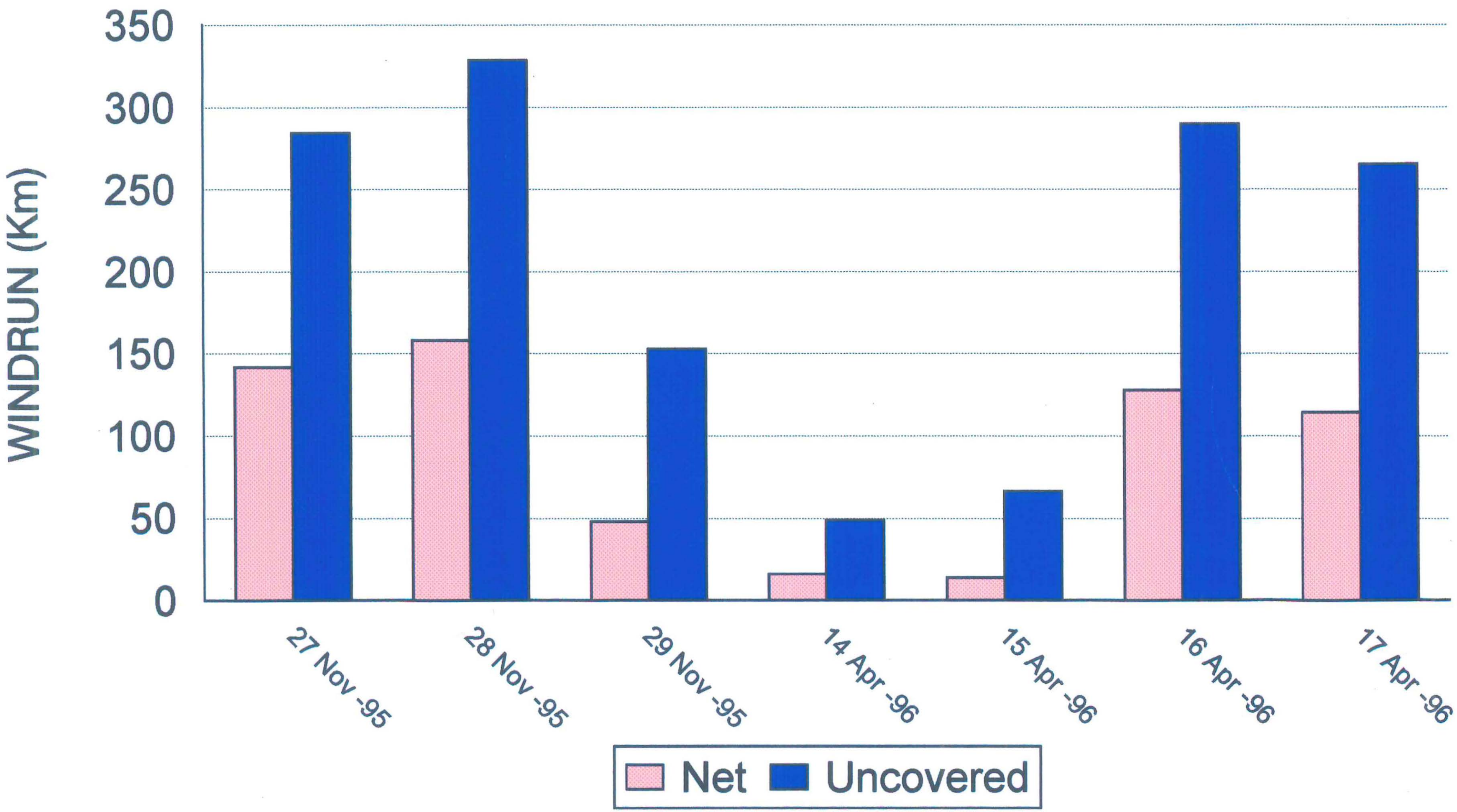
Table 3. Relative humidity (%) - Orange, NSW

Measured 160 cm above the ground and within the tree row, midway between two trees.

DECEMBER 1994			MARCH 1995		
	Black Net	Uncovered (open)		Black Net	Uncovered (open)
8 December 1994			**28 March 1995**		
6 am	58	**53**	6 am	100	**100**
9 am	60	**54**	9 am	100	**95**
12 noon	61	**59**	12 noon	58	**48**
3 pm	98	**91**	3 pm	52	**42**
6 pm	100	**98**	6 pm	68	**46**
9 December 1994			**29 March 1995**		
6 am	100	**99**	6 am	100	**94**
9 am	100	**100**	9 am	64	**52**
12 noon	100	**99**	12 noon	51	**42**
3 pm	92	**83**	3 pm	52	**43**
6 pm	85	**77**	6 pm	75	**61**
10 December 1994			**30 March 1995**		
6 am	100	**93**	6 am	100	**96**
9 am	81	**72**	9 am	78	**66**
12 noon	62	**57**	12 noon	59	**50**
3 pm	53	**52**	3 pm	52	**44**
6 pm	55	**48**	6 pm	78	**61**
11 December 1994			**31 March 1995**		
6 am	100	**95**	6 am	90	**81**
9 am	63	**52**	9 am	72	**63**
12 noon	40	**33**	12 noon	64	**54**
3 pm	38	**37**	3 pm	53	**45**
6 pm	46	**36**	6 pm	80	**67**

Figure 6. Reduction in wind speed under hail netting - Drouin VIC.

Anemometer was positioned at the edge of the tree canopy at a 180 cm height.



(b) Tree growth and productivity

As with the climatic measurements, the large amount of data collected from several experiments over five trial sites means that for practicality, only a representative selection of results can be presented here. Much of this work is ongoing as part of continuing project AP614 "Maximising apple orchard productivity under hail netting".

(i) Tree growth

On vigorous central leader Hi Early/Northern Spy trees at Orange, NSW and vase-pruned Granny Smith trees at Drouin, Vic, extension shoot numbers and shoot lengths were greater on trees under hail netting (Tables 4 and 5). Individual leaves under the net were also larger (Tables 4 and 5). All trees at each site were pruned identically, hence the dormant pruning of vigorous trees under net induced more regrowth the following season than the comparable pruning of unprotected trees. No such effects were measured at the Stanthorpe sites. Trees on the Granite Belt were of much lower vigour and measurements were made during two drought seasons, when water supplies and tree growth were minimal. Project AP614 is further investigating the inter-relationships between tree growth, pruning, irrigation, tree vigour and hail netting.

(ii) Fruit set

At all trial sites, fruit set was lower on trees under net (Figures 7 and 8), with fewer multiple fruit clusters occurring. Two chemical thinning sprays per season were used on the Hi Early trees under black net at Orange (Ethrel at full bloom and two weeks after full bloom) whereas three sprays were used on the uncovered trees (an additional NAA at full bloom). At all trial sites, less follow-up hand thinning was required on trees under net.

(iii) Fruit size and yield

For comparable crop loads, fruit on the uncovered vigorous trees at Drouin, Vic and Orange, NSW were larger than fruit under netting. The exception was in 1994/95 at Drouin (Figure 8), when average fruit weights were 127 g (open) and 131 g (net). Measures of fruit size distribution at Orange showed that in 1994/95 the same proportion of the crop was small (<68 mm diameter), regardless of the presence of netting (14% of apples on uncovered trees and 15% of those under net were small). The overall larger fruit on trees outside the net was instead due to a higher proportion of the crop being large (>76 mm diameter), with 31% of apples outside the net and just 22% of apples under net meeting this size. At trial sites on the Granite Belt, fruit on trees under net was of similar size or slightly larger than on uncovered trees (data not shown).

Hail netting had little effect on yields, with the exception of the Orange site, where average yields in 1994/95 and 1995/96 were 17 kg/tree lower under net (Figure 7). Despite lower initial fruit set, the average fruit weight of apples under net was 14 g (1995) and 7 g (1996) below that of apples from uncovered trees (Figure 7).

(iv) Fruit quality

The incidence of fruit windrub and sunburn is noticeably reduced by hail net. For example, in 1994/95, 8% of fruit on uncovered trees at the Orange site were sunburnt, compared to 1% of fruit under net. The occurrence of sunburnt fruit on the Granite Belt is higher (20%), with black netting at Site 3 reducing the incidence of sunburn to 4% of fruit, and white netting to 6-8% of fruit in 1994/95. It is particularly noticeable on the Granite Belt that the skin finish of Fuji apples is improved under hail netting.

Hail net can affect the fruit colour of red varieties, but this will depend on the location of apples in the tree. The colour intensity of Hi Early apples on trees under black netting at Orange has been slightly better than on fruit from uncovered trees (Table 6). Due to internal shading effects on fruit set, a higher proportion of fruit under black net may occur in "well-lit" parts of the tree where colour development is not adversely affected.

Measurements with the Effegi penetrometer on apples harvested from all sites showed no influence of hail netting on fruit firmness. Similarly, refractometer measures showed hail net to have little consistent effect on fruit sugar levels, except at Drouin, Vic in 1995/96, where Granny Smith fruit under the net were of 0.7-1.5% lower TSS (total soluble solids) than apples harvested from uncovered trees (Figure 9).

Fruit size and the location of apples within the tree canopy can both confound any effect of hail netting on sugar content, and make it difficult to directly attribute differences in fruit TSS to hail net. Additionally, the harvest of fruit at some trial sites at or past optimum maturity for the fresh market minimises potential large differences in sugar content that may be evident at earlier harvest dates.

Table 4. Shoot growth of Hi Early/Northern Spy trees in 1994/95 Orange, NSW. Planted in 1983.

Shoot Growth	Black Net	Uncovered
Shoot number (1 yo)/tree	49 ± 14	26 ± 7
Average shoot length (cm)	88.4 ± 10.0	62.8 ± 10.5
Total shoot growth (m/tree)	**43.1**	**16.1**
Average shoot leaf size (cm^2) (sample of 10 shoots/tree)	23	19

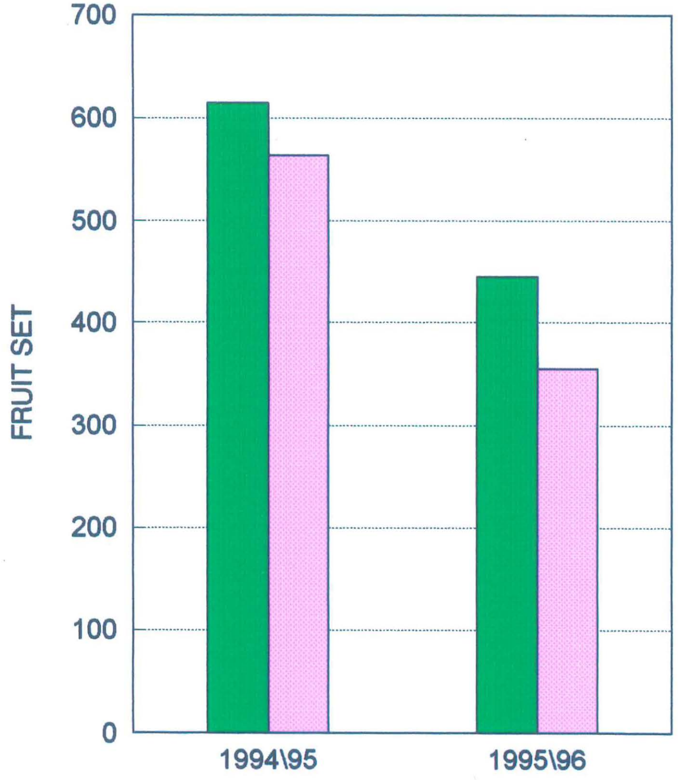
Table 5. Shoot growth of Granny Smith/Northern Spy trees in 1995/96 Drouin, Victoria

Shoot Growth	Black Net	Uncovered
*Shoot number/tree	7.2 ± 1.3	4.3 ± 1.1
Average shoot length (cm)	103.0 ± 9.5	88.0 ± 9.2
**Average leaf size (cm^2)		
:spur	37.3	29.4
:shoot	32.0	27.1

*Only internal watershoots of length >0.5 metres were counted
**1000 leaves per sample (100 leaves/tree x 10 trees, sampled from 1.25 m height on E side of trees).

Figure 7. Fruit set of Hi Early/Northern Spy trees

Orange, NSW.

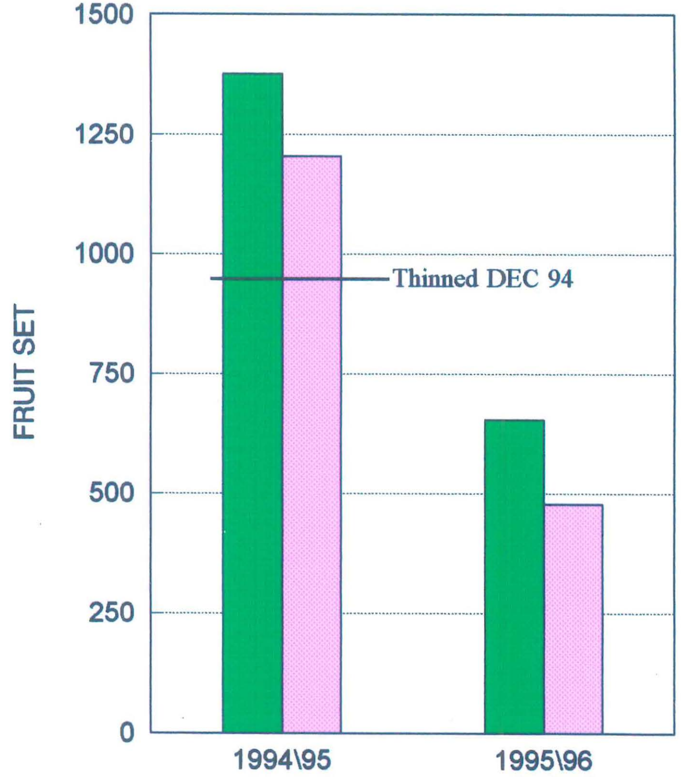


Average Fruit wt (g)	174	160	170	163
Yield (kg / tree)	91	74	68	51

Open Net

Figure 8. Fruit set of Granny Smith/Northern Spy trees

Drouin, Vic.



Average Fruit wt (g)	127	131	174	166

Open Net

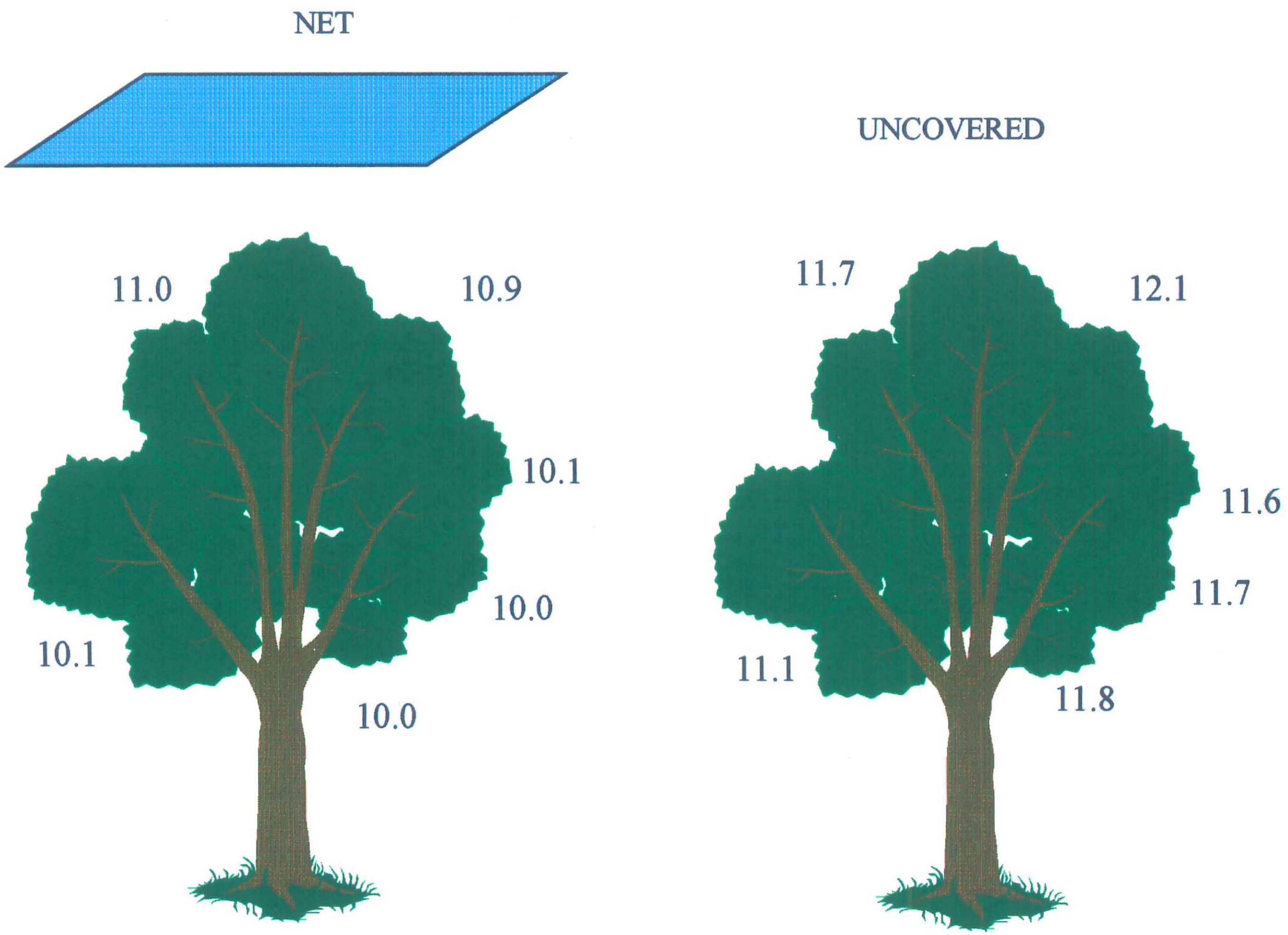
Table 6. The fruit colour of Hi Early Delicious apples harvested in March 1995 and March 1996 - Orange, NSW.

	Number of fruit in each colour class			
	***Poor (1, 2)**	**Medium (3)**	**Excellent (4, 5)**	**TOTAL**
MARCH 1995				
NET	163	761	1905	2829
	(5.8%)	**(26.9%)**	**(67.3%)**	(12 trees)
OPEN	311	1057	1997	3365
	(9.2%)	**(31.4%)**	**(59.3%)**	(12 trees)
MARCH 1996				
NET	313	1811	3238	5362
	(5.8%)	**(33.8%)**	**(60.4%)**	(16 trees)
OPEN	441	1500	2893	4834
	(9.1%)	**(31.1%)**	**(59.8%)**	(12 trees)

*Colour was assessed visually on a scale of 1 to 5, as illustrated in Appendix II. All fruit on each of the 12 or 16 trees was assessed.

Figure 9. Total soluble solids (% TSS) of Granny Smith apples harvested on 16 April 1996 - Drouin, Vic.

50 fruit per tree were sampled, with TSS measured on 8 to 10 fruit at each location.



Average (50 fruit) **10.5**

Average (50 fruit) **11.7**

(c) Tree management experiments

Preliminary trials to determine the appropriate management of tree under hail netting commenced in Project AP320. This work continues and is the major emphasis of current project AP614 "Maximising apple orchard productivity under hail netting". Hence, only a few of the initial results are presented in this final report, and are a prelude to the continuing project AP614.

(i) Crop Load

Fruit size is determined by many factors, including crop load, so to determine if hail net has any effect on fruit size it is necessary to standardise the crop load of trees. This was done at Site 1 (Orange), Site 2 (Drouin) and Site 3 (Stanthorpe) on the basis of hand thinning trees to a predetermined number of fruit per cm^2 TCA (trunk cross-sectional area), after fruit set was assessed. This accounts for the effect of tree size on potential crop load. Thus, for the same crop load treatment, a large tree of considerable canopy volume and leaf area (as indicated by TCA) is allowed to carry more fruit than a smaller tree, even though both trees are considered to have the same crop load.

Following fruit set counts in early December 1994, the Hi Early trees at Orange were hand-thinned to the crop loads shown in Table 7. The three crop load treatments were identical for trees under the net and out in the open, being 6.7, 4.9 and 3.2 fruit/cm^2 TCA for the heavy, medium and light crop loads respectively. There was some variation in fruit numbers per tree within these treatments (for example, the 'light' crop load averaged 272 fruit/tree under net and 323 fruit/tree in the open) due to small differences in tree size, as discussed previously. The same procedures were followed in the hand thinning of trees at Sites 2 and 3 (data not shown).

As expected, average fruit weight in March 1995 declined with increasing crop load, however for all three crop loads, the average fruit weight of apples harvested from trees protected by hail net was always less than that of apples from the uncovered trees (Table 7). Consequently, average yields under the net were also lower. These trends were repeated in 1996. The crop carried by trees in 1995/96 was to some extent determined by the 1994/95 crop loads (Table 7), consistent with the natural biennial bearing habit of the apple tree. Trees with a heavy crop in 1994/95 followed with a light crop in 1995/96. Of particular interest however, is that trees under net that had either a medium or light crop in 1994/95 had a noticeably smaller return crop in 1995/96 than the uncovered trees (medium crop - 280 fruit/tree under net compared with 410 fruit/tree in the open; light crop - 416 fruit/tree under net compared with 555 fruit/tree in the open).

Fruit size is also influenced by location within the tree canopy, and at all sites there was a steady decline in apple size with increasing canopy depth and distance from the top of tree. This was particularly noticeable within the vigorous trees at Orange, NSW, and at Drouin, Vic, as shown in Figure 10. At Drouin, apples at the bottom of the tree were only half the weight of those at the top of the tree. When yield and fruit weight data are presented for one metre height intervals (Figure 10) it is evident that there is little or no difference in average fruit weights within each height interval between trees under net and uncovered trees. The overall larger size of fruit picked from uncovered trees at Drouin was therefore mainly due to the higher proportion of the crop picked towards the top of the trees.

The yield and fruit weight results in Figure 10 can be attributed to light levels within the tree canopy. Readings from lightmeters set up at several identical positions within trees under net and outside net (Table 8) show that in late November, upper regions of the trees (location A) receive adequate light levels, whilst lower regions (locations C, D, E) receive inadequate light, regardless of the presence of netting. Although in the upper part of the tree, location B only receives sunlight during the afternoon; the 18% lower light (PAR) measured at this position under the net being the reduction in light due to the hail net itself. Light levels in April are reduced at all locations in the tree (Table 8) due to the lower angles of incident radiation in autumn (as solar altitude and azimuth decline), and the full development of the shoot leaf canopy by this time.

(ii) Pruning

A pruning trial commenced in 1995/96 at the Orange site, and continues in expanded form in project AP614 (sites in Qld and NSW). The pruning treatments described in the Materials and Methods (p 9) are part of an evaluation of tree management strategies to control the growth of excessively vigorous trees under hail netting, and improve the yields and fruit size of apples harvested from these trees. This is a major component of continuing project AP614, and it is too early to present results in this report.

It should be noted however, that trees left unpruned in winter 1995 "spurred up" considerably during 1995/96 and put on very little extension shoot growth. Fruit size and quality from the unpruned trees was relatively poor, as was the light distribution within them (Table 9). The trees unpruned in winter 1995 were heavily chunk-pruned in August 1996, to test whether regrowth could be minimised and vigour controlled by allowing trees to spur up heavily in one season, and then "chunk prune" the following winter prior to an anticipated heavy crop. The success or otherwise of this strategy, or indeed any of the other pruning treatments, (including an equivalent summer chunk pruning strategy) will be determined in project AP614.

Dormant pruning opens up trees to improved light penetration (Table 9), however regrowth must be minimised. As occurred in Drouin (Table 8), the light levels in Table 9 would be expected to decline later in the season as the leaf canopy fully develops and solar angles change. Nevertheless, it is obvious that light levels in lower regions of the canopy are very low and well below optimum, regardless of the presence of netting. Due to greater cumulative shoot growth following dormant pruning over several years, the internal regions of unpruned trees under net received less light than the corresponding regions of trees in the open (Table 9).

(iii) Bee activity

The introduction of beehives into orchards is generally necessary to ensure the adequate cross-pollination of apple trees, although natural bee populations at the Drouin site were high and usually sufficient to guarantee a good fruit set.

In the trial described on page 9, bee counts (30 second counts) made on 5 October 1994 (fine and warm) at Site 3 on the Granite Belt showed that bee activity declined during the morning (Table 10). At all times fewer bees were working trees under black net than trees outside the net. There was no such clear trend observed under the white net. This particular day was quite windy and the environment under the white net may have been more sheltered, and hence favoured bee activity longer into the day.

After approximately 11.00 am general bee movement within trees declined. The bees themselves moved more slowly and were concentrated in the tops of the trees, with little activity lower down. Bees working the trees towards the middle of the day tended to be pollen gatherers rather than nectar collectors. At this time a lot of guard bees were also evident at the entrances to hives, possibly due to low levels of nectar.

Observations were made on two other days: 6 October 1994 when conditions were very warm and still and the bees far more active, and on 7 October 1994 when it was overcast with drizzle, and only three bees in total were observed. The orchard monitored had a high density of hives. On the day prior to the introduction of hives, observations of trees under the net showed a maximum of one to two bees per tree, with most trees having no bee activity. Only with the introduction of honeybee hives was there a dramatic increase in bee populations.

Fruit set counts showed that the high density of hives in this particular orchard and their introduction just prior to full bloom ensured adequate pollination throughout the block. Under low-set gable net at site 4 however, considerable numbers of disorientated bees have been observed within the pitch of the hail net above trees, and this is raising concerns regarding the efficacy of pollination at this site. The activity and efficacy of bees under the "fixed net" structures used for hail protection in Queensland is generally of concern and is being further studied as part of continuing work on bee activity under hail netting in Project AP614.

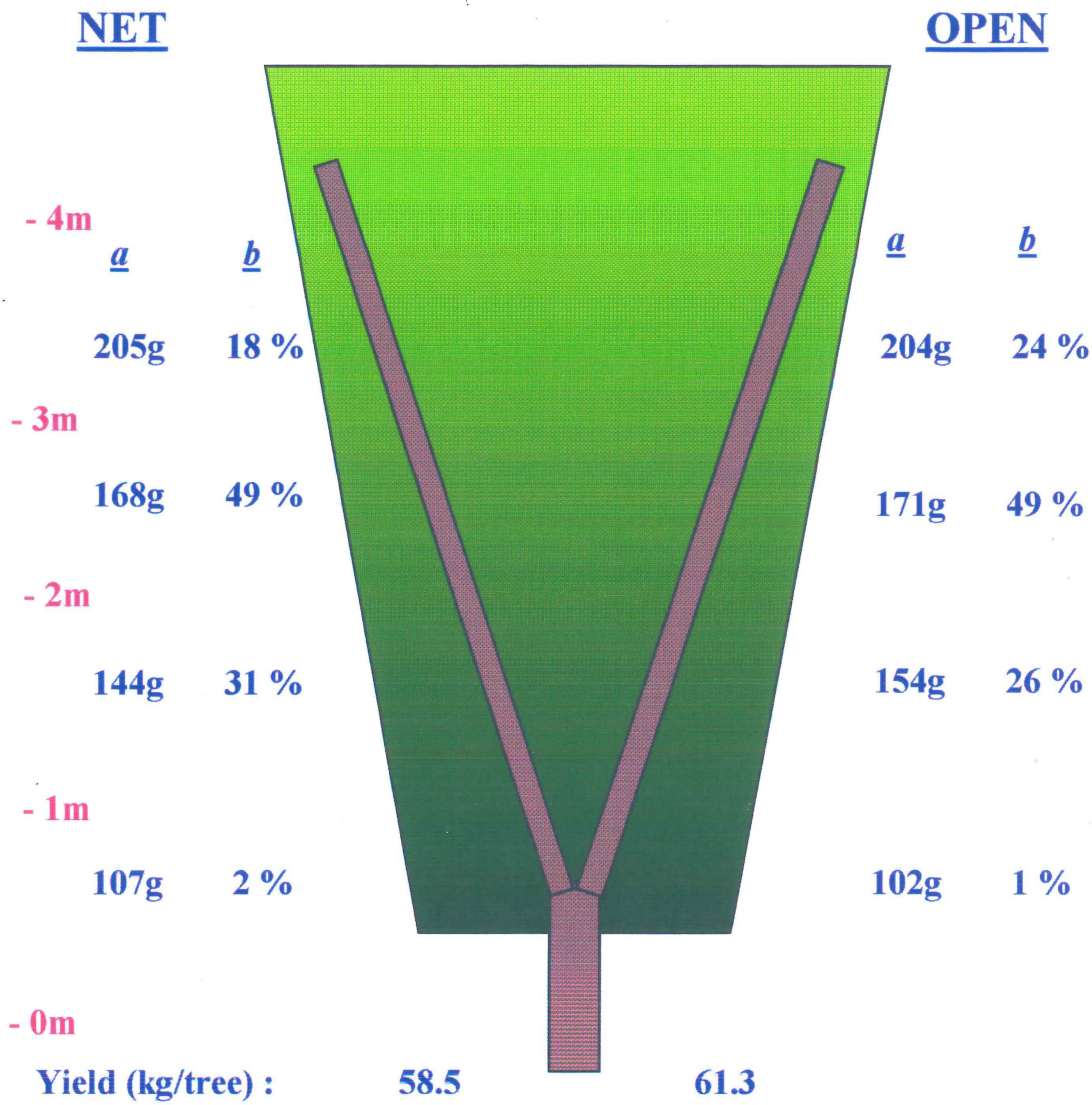
Table 7. The effect of hail netting and crop load on the yield and average fruit weight of Hi Early Delicious - Orange, NSW.

		1994/95				1995/96			
	Crop Load	*Fruit no/tree	Fruit no/cm^2 TCA	Yield (kg)	Average fruit wt (g)	Fruit no/tree	Fruit no/cm^2 TCA	Yield (kg)	Average fruit wt (g)
NET	Heavy	611	6.7	91.7	150.1	241	2.6	41.6	172.7
	Medium	503	4.9	79.8	158.6	280	2.6	47.2	168.6
	Light	272	3.2	50.7	186.3	416	4.9	64.1	154.0
	Average	**462**		**74.0**	**160.3**	**312**		**51.0**	**163.4**
OPEN	Heavy	608	6.7	102.8	169.1	243	2.6	45.8	188.3
	Medium	565	4.9	95.5	169.0	410	3.6	69.6	169.9
	Light	323	3.2	62.5	193.4	555	5.8	90.5	163.0
	Average	**523**		**91.0**	**174.1**	**403**		**68.6**	**170.2**

*Figures for each crop load treatment are the mean of 4 trees; hence the averages are for 12 trees under net and 12 trees in the open (uncovered).

Figure 10. The yield and fruit size distribution at 1 metre height intervals of Granny Smith harvested at Drouin, Vic in April 1996.

All the fruit from 9 trees under net and 9 trees in the open were assessed (3165 and 3169 fruit respectively)



a: average fruit weight

b: proportion of the crop harvested from each 1 metre height interval.

Table 8. Light (PAR) levels (mMoles) within vase-pruned Granny Smith trees at Drouin, Vic (38° 08'S)

	28 NOVEMBER 1995 - Alternating sun and cloud Above Net 39239 (100%) Under Net 31234 (79%)		16 APRIL 1996 - Alternating sun and cloud Above Net 16357 (100%) Under Net 12453 (76%)	
HEIGHT/LOCATION	BLACK NET	UNCOVERED	BLACK NET	UNCOVERED
A: 2.5m N external	21662 (55%)	24956 (64%)	4393 (27%)	5162 (32%)
B: 3.0m E 'inside vase'	9742 (25%)	16882 (43%)	1671 (10%)	4074 (25%)
C: 1.4m 'internal vase'	6192 (16%)	10582 (27%)	884 (5%)	2301 (14%)
D: 1.6m W underneath	7177 (18%)	5787 (15%)	930 (6%)	1701 (10%)
E: 1.8m SE underneath	3664 (9%)	3583 (6%)	584 (4%)	1251 (8%)

Table 9. The effect of dormant pruning on light levels (m Moles) within Hi Early Delicious trees at Orange, NSW (33° 19'S)

23 November 1995 - Fine, clear day.

Above net	49297	(100%)
Under net	37295	(76%)

	BLACK NET		OPEN	
Height/location	**Pruned Aug 1995**	**Unpruned**	**Pruned Aug 1995**	**Unpruned**
1.5 m W	19059 **(39%)**	2108 **(4%)**	21330 **(43%)**	10090 **(21%)**
1.25 m E	1190 **(23%)**	4270 **(9%)**	22615 **(46%)**	14711 **(30%)**
0.9 m E	6540 **(13%)**	2647 **(5%)**	9899 **(20%)**	4371 **(9%)**
2.2 m W	-	24043 **(49%)**	-	26962 **(55%)**

Table 10. Average bee numbers per tree observed on 5 October 1994

Time	Open (uncovered)	Black Net	White Net
9.00 - 9.30 am	8.3	5.5	5.8
9.30 - 10.00 am	6.4	5.5	4.7
10.00 - 10.30 am	5.5	4.1	4.9
10.30 - 11.00 am	4.3	3.9	4.7
11.00 - 11.30 am	4.6	4.1	5.1
11.30 - 12.00 noon	3.7	3.1	5.3
12.00 - 12.30 pm		2.8	
9.00 - 12.00 noon Average	5.5	4.4	5.1

Each value is the mean of 36 observations (9 trees x 4 observations per time period); each of 30 seconds duration.

DISCUSSION

The installation of hail net over an apple orchard immediately brings with it the economic necessity to produce the highest possible yields of premium quality fruit from the protected area of land, whilst minimising tree management and production costs. Yield is dependent on light interception (Jackson 1978), which in turn is a function of leaf area, whilst overall fruit quality is determined by the distribution of light within the tree canopy (Middleton 1990).

The hail netting of apple orchards reduces light levels (PAR) by 12 to 25%. Within this range, net colour, mesh size, diurnal weather conditions and the time of year influence light penetration through hail net. At the relatively low latitudes in which apples are grown in Australia, the reduction in light levels by hail netting was similar for orchards at Stanthorpe, Qld (28° 37′S), Orange, NSW (33° 19′S) and Drouin, Vic (38° 08′S).

The light reaching an apple tree, or indeed any other plant, consists of direct radiation from the sun and diffuse radiation scattered from the sky, haze and clouds (Monteith 1969). Diurnal variations in light penetration through hail netting will occur with changes in cloud cover (distribution and thickness) and the occurrence of particles in the air (dust, smog, fog), due to the effects of these factors on light scattering and the angles of incident light reaching the net. At low solar angles of incidence the scattering of light is greatest, and light penetration through hail netting is reduced. Reduced light penetration is likely due to more light reflected skywards after striking individual strands in the net from more horizontal angles (Gardner and Fletcher 1990).

Low solar angles of incidence occur early and late in the day when the sun is closer to the horizon, and during autumn as solar altitude and azimuth decline. Hence, late in the season there is a tendency for light penetration through net to be 2 to 3% lower than in mid-season (refer to Appendix III), and similarly the percentage light penetration was always lower early in the morning and late in the afternoon. This is generally of little practical significance as the light intensities at these times are much lower than during the rest of the day or in midseason, however there may be implications in the management of late season varieties if excessive tree vigour under net is preventing adequate colour development and delaying maturity.

Lightmeter readings were taken every six minutes, and the light levels plotted in Figures 1 to 5 are the summation of 10 readings taken over the previous hour. Light intensity is recorded as a light level per unit area per unit time (for example, mMoles cm^{-2} sec^{-1}), however light levels in Figures 1 to 5 are shown only as Moles. This is because the addition of 10 spot readings taken at regular intervals (to provide more meaningful and accurate data than a single hourly reading which may be momentarily affected by a random cloud) makes it erroneous to retain the units cm^{-2} sec^{-1}, unless an average value is presented.

Measurements of light in this project were always of photosynthetically active radiation (PAR), which is short-wave solar radiation of 400 to 700 nm wavelengths, and sometimes referred to as visible light. PAR provides the light energy for photosynthesis (Monteith 1969, Jackson 1980), the process by which apple trees produce photosynthates for tree growth and fruit development. Photosynthetically active radiation is very strongly absorbed by apple leaves, hence there is rapid attenuation of PAR within an apple tree and light levels in many parts of the canopy fall below 5 to 10% of incident levels regardless of the presence of netting.

Incident light levels in Australia are relatively high, 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. Heavy cloud cover and the apple tree canopy itself can however, 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 25% 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 shade levels. Tree vigour control under hail netting is therefore essential.

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. Measured fruit set reductions have not been large, but provide beneficial scope to reduce follow-up hand thinning. There is thus potential to use the shading effects of hail netting to encourage more self-regulating trees with low propensity to biennial bearing, and this is being investigated in continuing project AP614. Some success is being had in this with apple trees at one site on the Granite Belt, where vigour is well-controlled.

Hail net had little effect on yields, except at Orange, NSW where Hi Early trees under net consistently yielded less than the uncovered trees. Despite lower initial fruit set, the average fruit weight of apples under net at Orange was 14 g (1995) and 7 g (1996) below that of apples from uncovered trees. Shoot growth of the trees under net was excessive, and it seems that under conditions of adequate water, photosynthates were preferentially directed into shoot growth rather than fruitlet development. This has implications in the pruning, irrigation and crop load management of trees under net, and appropriate strategies to increase yields and maximise returns per hectare under net are currently being investigated.

Fruit quality and yield can vary considerably within the canopy of an apple tree, and exposure to light is the major factor contributing to this (Jackson 1980). The most commonly reported effects of shading within apple trees are reduced fruit size and colour (Middleton 1990), however other effects can include delayed maturity (Jackson *et al.* 1977), reduced soluble solids content (Doud and Ferree 1980) and reduced skin cracking and russet (Jackson *et al.* 1977).

At Orange, 15% of the fruit numbers under net and 14% of the apples on uncovered trees were small (<68 mm diameter). These proportions are similar, and show that even in uncovered trees light levels were poor in much of the canopy. At Drouin, the lower average fruit weight of apples under net was due to the lower average weight of apples harvested between 1 and 2 metres from the ground. At this height the cumulative shading effect of the hail net and the leaf canopy influenced fruit size, whereas above this height light levels were adequate, and below this height there was insufficient light, regardless of the presence of netting.

Lower fruit set under net could be due to several factors, including: (i) the influence of reduced light on spur quality and fruit bud differentiation, (ii) effects of net on bee activity and pollination, and (iii) improved efficacy of chemical spray thinning. It was particularly noticeable during flower counts at the Orange site in October 1995, that not only was there much less blossom under net, but full bloom of these trees was several days later than the uncovered trees. From observations of bee activity made in Granite Belt orchards it appears that the timing of the introduction of hives under hail netting with respect to tree floral stage is critical. This is being further studied in Project AP614, as the introduction of hives under net when blossom is unattractive to bees will only encourage them to seek a food (pollen and nectar) source from further afield, without adequately pollinating the trees nearby.

Apple maturity may be delayed under black net, which could be related to delayed blossoming. Hail netting may therefore provide a management tool to spread the harvest period of a particular apple variety and permit the harvest of the bulk of the crop at optimum maturity, whether for the fresh market or storage. Despite this, only once in this project was a consistent effect of hail net on total soluble solids measured. TSS is not necessarily a good indicator of apple maturity, and it would be useful to use other indicators such as starch:iodine ratings. Consistent differences in apple maturity at some sites may not have been detected as fruit were either harvested for the fresh market, or picked beyond optimum maturity.

Any effect of hail netting on temperature was minimal. Perceived cooler temperatures under black net are due to reduced radiation; similarly, perceived higher temperatures under white net on hot days are due to reflected light. Air temperature measures inside a Stevenson screen give "true" readings without the confounding effects of wind and radiation, and this is the standard, accepted means of temperature measurement (Australian Bureau of Meteorology 1975). Temperature measures using a sensor with an exposed tip include the influence of wind and radiation, and give some indication of our personal perception of temperature.

Hail netting does not provide frost protection. The frosts that occur in Australia are commonly 'radiation' frosts. Heat that is absorbed during the day by the earth's surface and air close to the ground is radiated upwards during the night (Australian Bureau of Meteorology 1975). Cloud cover at night will absorb and re-radiate much of this energy back to the earth's surface, however under clear sky conditions if the temperature falls low enough, the progressive overnight loss of heat energy to the atmosphere will lead to frost formation towards dawn. As air near the ground cools and becomes denser it may flow down slopes into gullies and 'frost hollows' as a katabatic wind (Australian Bureau of Meteorology 1975).

For frost protection it would therefore be necessary for net to prevent the escape of heat energy to the atmosphere and the flow of cold air down slopes. Obviously, the mesh size of hail net allows these processes to still occur. If netting were to provide some guarantee of frost protection and re-radiate escaping heat energy back down to the ground, it would need to be of such a small mesh size that the high shade factor would make it unsuitable for commercial apple production.

Higher humidity under net increases the length of time leaves remain wet after either rainfall or spraying. Campbell (1991) noted that the incidence of black spot (*Venturia inaequalis*) under net was no greater than on trees outside net, and observations in orchards on the

Granite Belt confirm this. These observations however, have been made in two dry seasons when the incidence of black spot was low, and control relatively easy. As part of the Black Spot Warning Service available to growers on the Granite Belt, measurements from a weather station under hail net are now also included in the prediction of primary infection periods.

The higher humidity and reduced wind under hail net can be expected to contribute to an increase in spray efficacy through a twofold effect: (i) slower drying times that permit improved chemical absorption by leaves, and (ii) facilitating timely spray applications under windy conditions that would otherwise prevent the spraying of uncovered trees. Pan evaporation in a Japanese pear orchard under hail net was reduced by an average 1 mm per day (Kon *et al.* 1989), and although not measured in this project, reduced evaporation under hail net of at least this magnitude should occur under the hot, dry conditions in which apples are produced Australia. With reduced evaporative water losses, improvement in tree water use efficiency are expected under hail net. An EnviroScan system is currently being used on the Granite Belt to monitor and compare the water use in adjacent blocks of young apple trees, where one block is under black hail net and the remaining trees are uncovered.

Growers with netted orchards need to rapidly attain and maintain high production levels to recoup their financial outlay on hail netting, and high-yielding intensive systems for apple production are ideally suited to protection by hail net. This project was in part undertaken to identify potential benefits of apple orchard hail netting aside from the primary objective of fruit and tree protection from hail damage. It is continuing as Project AP614 to show how productivity gains, and reductions in management inputs, are possible with full exploitation of the hail net microclimate. Only with increased adoption of netting in hail-prone regions can guarantees of apple supply (in terms of both volume and fruit quality) be made to ever-discerning markets.

CONCLUSIONS

- Hail netting reduces light (PAR) by up to 25%, however the leaf canopy itself can reduce light levels by up to 95% in some parts of the apple tree, regardless of the presence of netting.

- Reductions in light beneath hail netting are significant, but manageable. Daily weather conditions (cloud cover) and seasonal changes in solar altitude and azimuth also significantly influence the light levels incident on trees.

- Hail net reduces wind by 50% or more, and may increase humidity by up to 15%. Net has little or no effect on temperature and does not offer frost protection.

- Apple tree response to hail net is determined by vigour.

  - **Vigorous trees under net**: greater shoot growth (more shoots, longer shoots, longer leaves) and smaller fruit than comparable uncovered trees.

  - **Dwarf to semidwarf trees under net**: shoot growth has been no different, and fruit are of similar size or larger than on comparable trees outside net.

- Control of tree vigour under hail netting is essential, and mistakes in tree pruning are exacerbated under net.

- Fruit set is reduced under hail net, with fewer multiple clusters. There is scope to use this to advantage in minimising follow-up hand thinning. Hail net has a variable effect on yield, as influenced by tree vigour and bee activity/pollination.

- The effect of hail netting on the colour development of red varieties is variable, and is determined by tree vigour and fruit position in the canopy. Windrub and sunburn of fruit is reduced by net.

- The management of trees under hail net needs to consider:

- Pruning	- Crop load, thinning
- Irrigation	- Pollination/bee activity

- Pruning, irrigation and crop load strategies for trees under hail net must aim to:

  - control tree vigour
  - maintain good light distribution throughout the canopy
  - maximise yields, fruit size and quality.

FUTURE RESEARCH

(a) Control of tree vigour under hail netting

- The use of management techniques such as pruning, irrigation and crop load manipulation to improve the yields and fruit size on vigorous trees protected by hail netting.

(b) Maximise the productivity of netted orchards

- This includes the control of tree vigour as above, but also needs to consider how to increase yields and fruit quality produced from all netted orchards, as well as reduce orchard management costs through options such as improved irrigation efficiency, reduced hand thinning etc. Physiological studies of tree water use and photosynthesis are included.

(c) 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.

(d) Bee activity/pollination

- Determine hive densities and arrangements, and the siting of polleniser varieties appropriate to the behaviour and activity of bees under hail netting. This is of particular relevance beneath the "fixed" hail net structures used in Queensland.

(e) Economic analyses

- '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, ability to spray under windy conditions, lower water use, reduced sunburn, hand thinning etcetera.
- Costs and returns to determine what yields/packout are required before it is economically feasible to consider netting an orchard block.

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APPENDIX I. HAIL NET TYPES

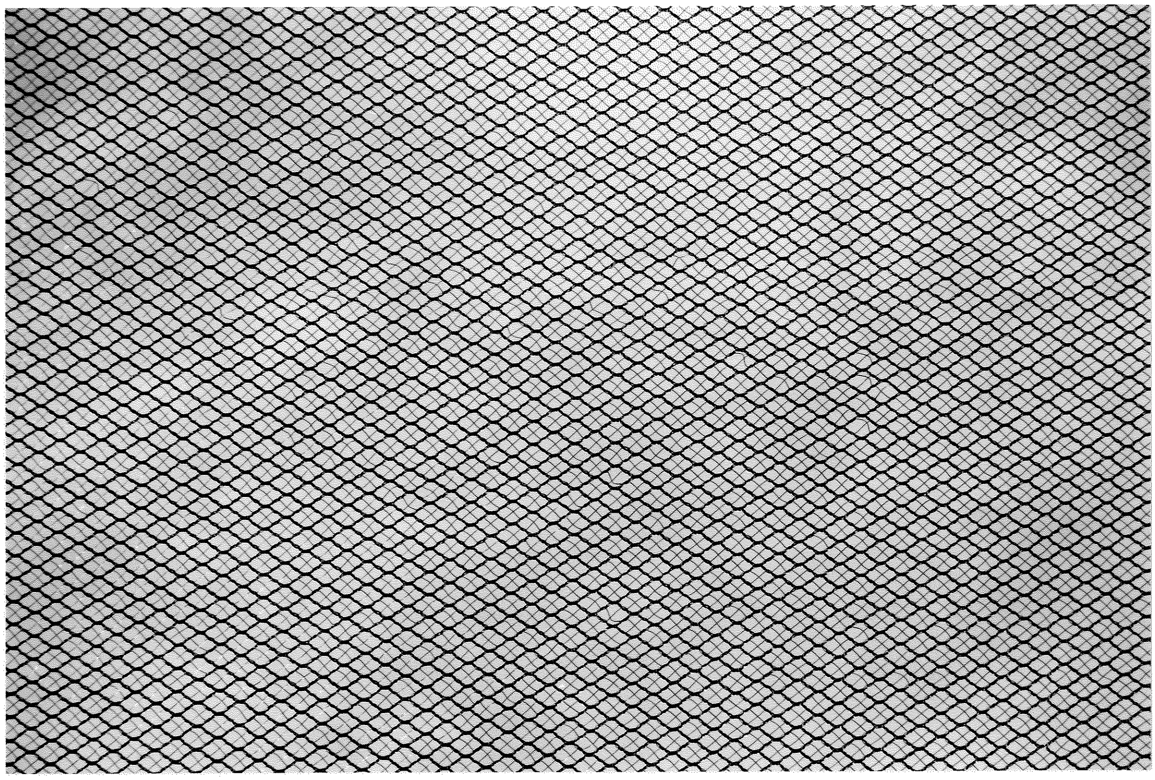

Plate 1. Close-up of the black hail net mesh at Site 1 (Orange, NSW)

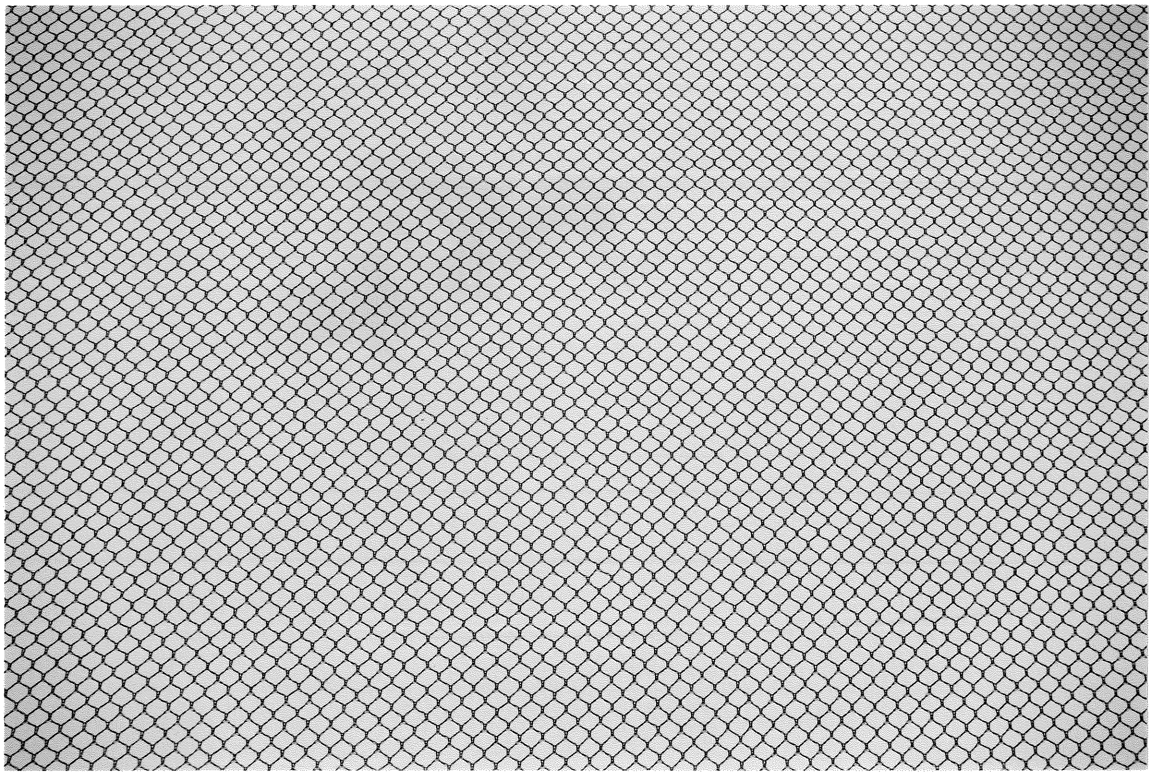

Plate 2. Close-up of the black hail net mesh at Site 2 (Drouin, Vic)

Plate 3. White Hailgard netting above Fuji trees at Site 3 (Granite Belt, Qld). This net type was also used at Site 4. Three lightmeters are visible in the centre of the photograph, and are measuring the light penetration (PAR) through the hail netting.

APPENDIX II. FRUIT COLOUR AND SUNBURN CLASSES

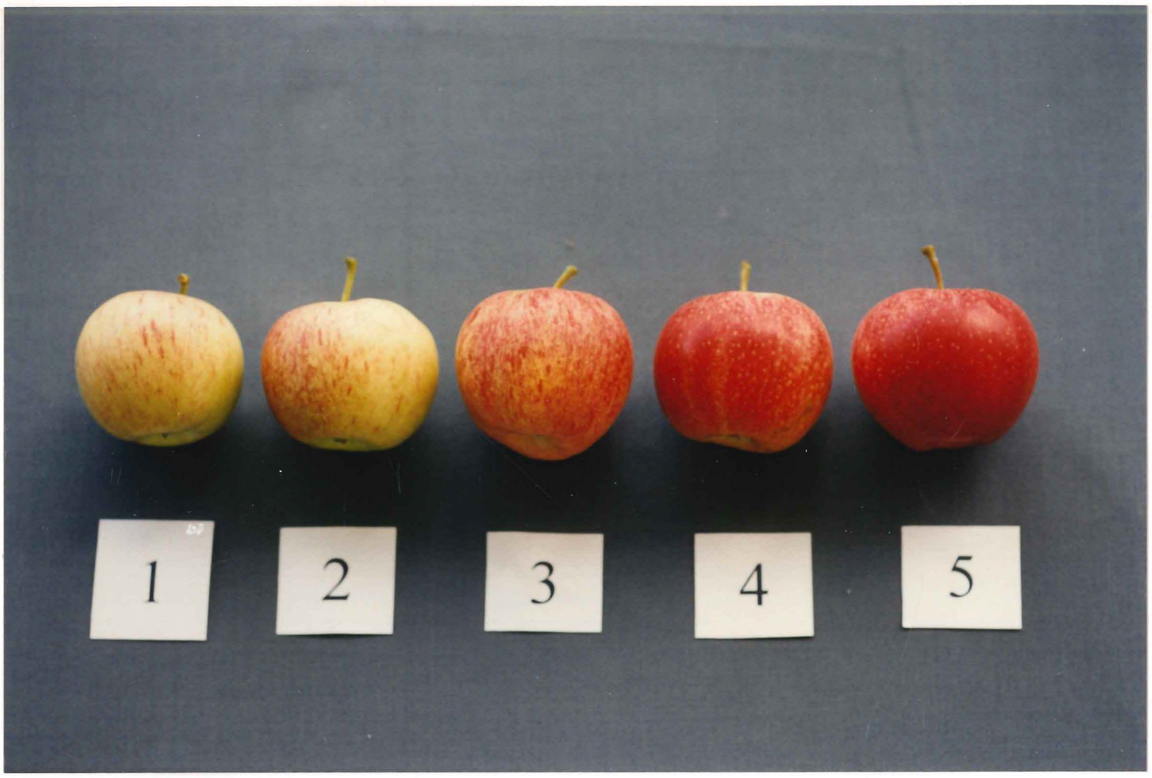

Plate 1. Rating classes used to visually assess the colour of Gala apples. The colour variation between the apples in this photo can occur within a single tree.

Plate 2. The ratings used to visually assess the incidence of sunburn on Granny Smith

APPENDIX III. LIGHT PENETRATION THROUGH HAIL NETTING

TABLE 1. DROUIN, VIC (38° 08 'S)

	ABOVE NET *PAR (mMoles)	UNDER NET *PAR (mMoles)	% LIGHT PENETRATION	WEATHER
(a) BLACK NET				
27 Nov 1995	61713	50543	**81.9**	Fine, 100% blue sky
28 Nov 1995	39239	31234	**79.6**	Alternating sun and cloud
29 Nov 1995	25209	19708	**78.2**	Mainly overcast
14 April 1996	7498	5979	**79.8**	Overcast, showers
15 April 1996	16583	12244	**73.8**	Alternating sun and cloud
16 April 1996	16357	12453	**76.1**	Alternating sun and cloud
17 April 1996	5397	4355	**80.7**	Heavy rain, dull
(b) WHITE NET				
1 Dec 1995	46111	40262	**87.3**	Sunny with occasional cloud
2 Dec 1995	59051	51915	**87.9**	Fine, slight cloud in pm
3 Dec 1995	47652	42020	**88.2**	AM fine and clear, PM cloud buildup

*Photosynthetically Active Radiation - Light readings were taken every six minutes between sunrise and sunset.

TABLE 2 LIGHT PENETRATION THROUGH HAIL NETTING - GRANITE BELT, QLD (28° 37'S)

DATE	ABOVE NET	WHITE NET		BLACK NET		WEATHER
	* PAR (mMoles)	* PAR (mMoles)	%Light Penetration	* PAR (mMoles)	% Light Penetration	
10 Jan 1995	48163	41577	**86.3**	36799	**76.4**	AM overcast, PM fine
11 Jan 1995	53040	46394	**87.5**	40813	**77.0**	Fine with high patchy clould
12 Jan 1995	56283	48814	**86.7**	43974	**78.1**	Fine with high patchy clould
13 Jan 1995	66795	58466	**87.5**	52334	**78.4**	Fine, clear
14 Jan 1995	67541	58635	**86.8**	51205	**75.8**	Fine, clear
15 Jan 1995	57553	50180	**87.2**	43889	**76.3**	Fine, some haze
16 Jan 1995	59109	50645	**85.7**	44108	**74.6**	Fine, occasional cloud
17 Jan 1995	47148	40283	**85.4**	35998	**76.4**	High, light cloud 6-8/8
18 Mar 1995	50405	41786	**82.9**	38609	**76.6**	Fine, clear
19 Mar 1995	41545	34789	**83.8**	31716	**76.3**	AM fine, PM storm cloud
20 Mar 1995	49902	41091	**82.3**	37691	**75.5**	Fine, clear

* Photosynthetically Active Radiation - Light readings were taken every six minutes between sunrise and sunset.

APPENDIX IV. EFFECT OF HAIL NETTING ON TEMPERATURE

TABLE 1. AIR TEMPERATURE (°C) - ORANGE, NSW

Measured 160 cm above the ground and within the tree row, midway between two trees.

DECEMBER 1994	Black Net	Uncovered (open)	MARCH 1995	Black Net	Uncovered (open)
8 December 1994			**28 March 1995**		
6 am	16.3	**16.8**	6 am	5.5	**6.0**
9 am	21.3	**21.9**	9 am	12.1	**12.4**
12 noon	22.7	**23.1**	12 noon	18.3	**19.3**
3 pm	13.9	**13.9**	3 pm	18.5	**19.3**
6 pm	12.6	**12.7**	6 pm	8.6	**10.5**
9 December 1994			**29 March 1995**		
6 am	7.4	**7.4**	6 am	0.9	**1.2**
9 am	7.9	**7.9**	9 am	12.4	**13.5**
12 noon	9.3	**9.2**	12 noon	16.7	**17.7**
3 pm	11.9	**12.0**	3 pm	14.8	**15.2**
6 pm	10.9	**11.2**	6 pm	9.5	**10.7**
10 December 1994			**30 March 1995**		
6 am	2.8	**2.8**	6 am	1.2	**1.3**
9 am	11.1	**11.2**	9 am	12.2	**13.0**
12 noon	16.5	**16.8**	12 noon	16.1	**16.9**
3 pm	19.2	**19.4**	3 pm	17.7	**18.5**
6 pm	17.2	**18.4**	6 pm	9.9	**11.3**
11 December 1994			**31 March 1995**		
6 am	4.5	**4.8**	6 am	6.3	**6.6**
9 am	15.7	**17.2**	9 am	10.7	**11.3**
12 noon	20.5	**20.7**	12 noon	11.6	**11.9**
3 pm	23.7	**24.0**	3 pm	14.4	**14.5**
6 pm	21.6	**23.1**	6 pm	7.8	**8.9**

TABLE 2. SOIL TEMPERATURE (°C) - ORANGE, NSW

DECEMBER 1994	Black Net	Uncovered (open)	MARCH 1995	Black Net	Uncovered (open)
8 December 1994			**28 March 1995**		
6 am	15.8	**16.5**	6 am	11.7	**13.1**
9 am	16.0	**17.2**	9 am	12.2	**13.5**
12 noon	17.0	**18.3**	12 noon	13.4	**14.4**
3 pm	17.0	**18.0**	3 pm	13.9	**15.5**
6 pm	16.1	**16.7**	6 pm	13.6	**15.4**
9 December 1994			**29 March 1995**		
6 am	13.9	**14.2**	6 am	10.6	**12.0**
9 am	13.1	**13.3**	9 am	11.0	**12.5**
12 noon	13.1	**13.3**	12 noon	12.3	**13.3**
3 pm	13.8	**14.2**	3 pm	13.1	**14.8**
6 pm	14.0	**14.4**	6 pm		**14.6**
10 December 1994			**30 March 1995**		
6 am	11.5	**11.6**	6 am		**11.8**
9 am	11.7	**12.3**	9 am		**12.2**
12 noon	13.9	**14.6**	12 noon		**13.1**
3 pm	15.2	**16.0**	3 pm		**14.6**
6 pm	17.1	**18.0**	6 pm		**14.6**
11 December 1994			**31 March 1995**		
6 am	13.4	**13.6**	6 am		**12.5**
9 am	13.4	**14.0**	9 am		**12.7**
12 noon	14.9	**17.0**	12 noon		**13.3**
3 pm	21.0	**22.0**	3 pm		**14.8**
6 pm	19.9	**19.4**	6 pm		**14.5**

TABLE 3. AIR TEMPERATURES (^oC) UNDER HAIL NETTING GRANITE BELT, QLD

DATE	MAXIMUM		MINIMUM		AVERAGE	
	WHITE NET	**BLACK NET**	WHITE NET	**BLACK NET**	WHITE NET	**BLACK NET**
6 Jan 95	28.5	**28.5**	14.5	**14.6**	20.5	**20.6**
7 Jan 95	28.4	**28.5**	14.4	**14.5**	20.3	**20.4**
10 Jan 95	23.7	**23.6**	13.7	**13.8**	17.4	**17.6**
11 Jan 95	23.2	**23.2**	13.4	**13.5**	17.1	**17.3**
12 Jan 95	24.8	**24.8**	12.3	**12.5**	17.1	**17.3**
15 Jan 95	28.6	**28.3**	12.8	**13.0**	18.7	**18.9**
16 Jan 95	29.4	**29.5**	12.7	**12.8**	20.2	**20.2**
17 Jan 95	27.0	**27.3**	13.4	**13.5**	19.6	**19.8**
MEAN	***26.7***	***26.7***	***13.4***	***13.5***	***18.9***	***19.0***
17 Mar 95	24.5	**24.2**	11.2	**11.3**	16.2	**16.6**
18 Mar 95	25.4	**25.7**	12.4	**12.7**	18.2	**18.5**
19 Mar 95	26.8	**26.9**	11.9	**12.1**	18.2	**18.5**
21 Mar 95	25.7	**26.0**	11.1	**11.3**	16.8	**17.1**
MEAN	***25.6***	***25.7***	***11.7***	***11.9***	***17.4***	***17.7***

TABLE 4. MAXIMUM AIR TEMPERATURES (°C) - GRANITE BELT, QLD

Measured 160 cm above the ground and within the tree row, midway between two trees.

	BLACK NET		WHITE NET	
	Screen (standard)	**Exposed tip**	**Screen (standard)**	**Exposed tip**
JANUARY 1995				
6 Jan	28.5	31.4	28.5	32.4
7 Jan	28.5	31.6	28.4	32.7
8 Jan	23.2	27.2	22.5	27.0
9 Jan	23.3	27.6	22.5	27.2
10 Jan	23.6	28.5	23.7	27.4
11 Jan	23.2	27.5	23.2	27.1
12 Jan	24.8	29.3	24.8	29.1
13 Jan	24.1	28.4	23.2	27.5
14 Jan	24.8	29.6	24.0	28.7
15 Jan	28.3	31.2	28.6	33.7
16 Jan	29.5	33.2	29.4	32.9
17 Jan	27.3	30.1	27.0	30.0
MARCH 1995				
17 March	24.2	29.0	24.5	30.0
18 March	25.7	30.1	25.4	29.5
19 March	26.9	30.3	26.8	30.9
20 March	23.6	29.8	23.1	29.2
21 March	26.0	31.3	25.7	31.4

APPENDIX V. SAMPLE PRINTOUT OF HOURLY WEATHER DATA

Readout Date was 12/12/94 08:57:18
MONITOR LL-128 J049224 30/12/93
Logger was moved to Gala White Net on Thursday and the reset on Sat 19-11-94 at 3.59pm
DAY# 5 08;58;12
839 1123 56 1056 145 1015 30 60
ORANBNET.XLS

METEOROLOGICAL MEASURES - BLACK HAIL NET - ORANGE NSW

		ABOVE TREE PAR	ABOVE TREE PAR	OUTER WEST PAR	OUTER EAST PAR	INNER N LOW PAR	OUTER E LOW PAR	MIDDLE SW PAR	MIDDLE NW PAR	CENTRAL S LOW PAR		HUMIDITY	WIND	SMALL SCREEN TEMP	EXPOSED TEMP
		Ch#0	Ch#1	Ch#2	Ch#3	Ch#4	Ch#5	Ch#6	Ch#7	Ch#8	Ch#9	Ch#10	Ch#11	Ch#12	Ch#13
	8-Dec-94														
	01;00;00	0	0	0	0	0	0	0	0	8	0	71.2	0	12.3	12.7
	02;00;00	0	0	0	0	0	0	0	0	8	0	69.3	0	12.8	13.1
	03;00;00	0	0	0	0	0	0	0	0	12	0	69.5	0	13.1	13.4
	04;00;00	0	0	0	0	0	0	0	0	12	0	65.8	2.1	14.5	14.8
	05;00;00	0	0	0	0	0	0	0	0	12	0	61.9	7	15.7	15.9
	06;00;00	103	108	26	42	5	39	14	8	20	0	56.5	14.6	16.7	16.8
	07;00;00	2157	2051	477	881	169	746	378	244	214	0	61.1	5.1	15.8	16.0
	08;00;00	11085	10124	1279	3404	717	2721	1045	839	1022	0	65.8	5.4	17.2	18.8
	09;00;00	31905	29907	3688	15665	1914	12959	2532	9892	4743	0	62.7	12.4	21.0	23.9
	10;00;00	35252	34064	6377	25275	3876	20208	4432	4820	4024	0	59.3	14	21.5	23.4
	11;00;00	35852	34599	5449	27232	4384	16645	5660	4123	6470	0	62.6	9.6	20.9	22.7
	12;00;00	40321	39468	13623	22722	4492	17852	7220	5119	2207	0	64.9	8.5	22.0	23.5
	13;00;00	32779	32417	12596	13197	3817	13623	6370	4505	1968	0	62.7	12.9	21.8	22.9
	14;00;00	11155	11043	3265	4730	1262	4234	2558	1689	857	0	69.5	16.5	18.4	18.7
	15;00;00	9351	9352	2994	4142	1009	4021	2266	1371	793	0	92.5	25.5	14.3	14.1
	16;00;00	4576	4595	1473	1905	486	2047	1125	656	422	0	100.6	13.4	13.2	13.1
	17;00;00	2970	2985	984	1198	312	1342	755	412	369	0	101.9	8.1	12.2	12.1
	18;00;00	3171	3214	1038	1277	345	1434	802	443	971	0	103.7	12.7	12.1	12.5
	19;00;00	2465	2509	804	1006	258	1107	615	341	831	0	105.3	0	12.6	12.7
	20;00;00	647	661	207	254	64	287	158	80	477	0	105.4	0	12.6	12.6
	21;00;00	3	2	2	0	0	0	0	0	4	0	105.4	0	12.3	12.2
	22;00;00	0	0	0	0	0	0	0	0	0	0	105.7	0.5	12.0	11.9
	23;00;00	0	0	0	0	0	0	0	0	0	0	106.3	0.5	12.0	12.0
2	00;00;00	0	0	0	0	0	0	0	0	0	0	106.3	3.3	11.8	11.8
	TOTALS	223792	217099	54282	122930	23110	99265	35930	34542	25444		80.7	172.1	15.4	15.9
% light penetrating the net		100.0	100.0	24.6	55.8	10.5	45.0	16.3	15.7	11.5		AVERAGE		AVERAGE	AVERAGE
% of light above the net		78.9	76.5	19.1	43.3	8.1	35.0	12.7	12.2	9.0					