Avocado canopy and orchard floor management

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FINAL REPORT

AV00007
Avocado Canopy and Orchard Floor Management

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This document is a final report containing the results and recommendations from a research program that investigated canopy management strategies involving mechanical pruning and growth retardant application. The effect of various mulching products on yield and fruit quality was also investigated.

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Media Summary

Canopy management is a significant challenge for the Australian avocado industry. The avocado tree must produce new growth each year to remain productive. However, if left unchecked the orchard eventually becomes crowded with a loss in fruit quality and yield. Large trees are also difficult to harvest and spray. Flowering and fruiting occur in well-lit terminal sites on the surface of the canopy. In crowded orchards the productivity of side canopies is lost due to insufficient light reaching lower levels of the tree.

The 'Avocado Canopy and Orchard Floor Management (AV00007)" project was carried out to develop pruning systems that controlled tree size but with minimal negative effects on tree yield and fruit. Mechanical pruning systems were used because of their cost efficiency. Factors such as the time of pruning were investigated. Several chemicals that are known to reduce tree growth were also evaluated. Other treatments to improve fruit quality from pruned trees were studied, including calcium treatments and mulching.

Research was primarily conducted on 'Hass' grown in warm subtropical southeast Queensland (Childers/Bundaberg). Pruning trials were also conducted on 'Shepard' on the Atherton Tableland in north Queensland. The research found that:

- Pruning can control tree size, however the timing of pruning will determine the success of this canopy management strategy.
- Yield was reduced in trees pruned for the first time, but this effect was minimal after 2-3 years.
- Trees should be pruned after harvest and prior to the onset of flowering to minimise flower removal and maximise yield.
- Pruning can stimulate vegetative growth, and the timing of the post-harvest prune will influence the amount of regrowth during flowering and fruit set. Pruning trees 1-2 months after harvest reduced vegetative growth and maintained fruit quality.
- The success of summer pruning is dependent on establishing a tree shape at fruit set so that further pruning can be implemented in the presence of the crop.
- The timing of the summer prune influences the length of shoot regrowth and the size of the canopy. Trees should be pruned no later than December to avoid reduced flowering in shoots the following spring
- Foliar application of Sunny® at flowering increased fruit size by 7-16% but generally did not increase final tree yield. Sunny® applied to the regrowth following summer pruning can reduce shoot length and increase flowering the following spring.
- Pruning can reduce the concentration of Ca in the fruit. Low fruit Ca has been associated with poor fruit quality.
- Apogee® (prohexadione-calcium) when applied at flowering increased fruit quality. Application of NAA to branches following pruning reduced regrowth in the treated area however regrowth occurred further down the branch.
- Mulching enhanced root activity and improved fruit quality, but no increase fruit size or yield was observed.

The results of this research provide information on canopy management strategies involving pruning and growth regulator application on 'Hass' and 'Shepard' avocado in warm subtropical climates. Further work is required in other production areas before industry-wide recommendations can be made.

Technical Summary

Trials were established to investigate the effect of pruning and uniconazole (Sunny®, Sumitomo Chemicals Australia Pty Ltd) on shoot growth, flowering, yield and fruit quality of 'Hass'. Trees were mechanically pruned at an angle of 15-20° to form a pyramid following the harvest in June-September and during the summer following maturation of the spring growth flush in December-February. Sunny® was sprayed at flowering and to regrowth following summer pruning.

Pruning can control tree size; however the timing of pruning will determine the success of this canopy management strategy. Yield was reduced by 39-56% in trees pruned for the first time, but after 2-3 years there was no difference in yield between pruned and unpruned trees. Trees should be pruned after harvest and prior to the onset of flowering to minimise yield losses due to removal of inflorescences.

Pruning can stimulate vegetative growth and the timing of the post-harvest prune will influence the amount of regrowth during flowering and fruit set. In the warmer production areas where the harvest is completed before flowering, pruning soon after harvest can induce vegetative growth that may compete with the developing fruit and reduce fruit quality. In southeast Queensland pruning 'Hass' immediately after harvest increased regrowth and the incidence of fruit body rots compared with unpruned trees. However, there was no significant effect of pruning two months after harvest on regrowth and body rots compared with unpruned trees, suggesting that pruning 1-2 months after harvest is preferred to pruning directly after harvest. In north Queensland, pruning 'Shepard' immediately after harvest also increased regrowth and reduced yields. Pruning 1-2 months after harvest is also recommended with no effect on yield.

The success of summer pruning is dependent on establishing and maintaining a tree shape at fruit set so that further pruning can be implemented in the presence of the crop. The timing of the summer prune influences the length of shoot regrowth with maximum shoot growth in trees pruned in December. Pruning in mid to late summer in southeast Queensland reduced the proportion of shoots that flowered the following spring. For example, at one site 55 and 43% of the shoots flowered in trees pruned in January and February, respectively compared with 88% in unpruned trees. Therefore summer pruning is a compromise between controlling shoot growth and reducing the risk of removing flowering wood. Trees should be pruned no later than December to avoid reduced flowering in shoots the following spring.

Foliar application of Sunny® at flowering increased fruit size by 7-16% but generally did not increase final tree yield. Sunny® applied to the regrowth following summer pruning often reduced length and increased flowering the following spring.

Pruning after harvest reduced the Ca concentrations in the fruit. Low fruit Ca has been associated with poor fruit quality. Foliar Ca (Calcimax®) increased the Ca concentration in the fruit in pruned trees at one site, but generally had little effect on fruit quality. Other soil or foliar treatments had no effect on fruit Ca concentration or fruit quality.

Preliminary data suggests that prohexadione-calcium (Apogee®) and naphthalene acetic acid may be useful canopy management tools. Mid-bloom foliar applications of Apogee at 1.25 g/l reduced in the incidence of body rots with 12% of the fruit affected compared with

25 % in untreated trees. Application of NAA to branches following pruning reduced regrowth in the treated area however regrowth was encouraged further down the branch. Further trials on the effect of prohexadione-calcium and NAA are being conducted.

The effect of mulching on fruit size and yield in 'Hass' avocado was investigated in subtropical southeast Queensland. Although mulching did not increase fruit size or yield, enhanced root activity and improved fruit quality was observed. At one site, the addition of woodchip and pine-bark reduced the severity of diffuse discolouration with 0.9 and 1.2% of the fruit flesh affected compared with 2.1% in the unmulched trees.

This research was conducted on 'Hass' in southeast Queensland and 'Shepard' in north Queensland. Further work is required in other production areas before industry-wide recommendations can be made.

1 Effects of pruning and Sunny® on growth, flowering, yield and fruit quality in 'Hass'

1.1 Introduction

Canopy management is one of the major issues confronting the Australian avocado industry. Due to its flowering and fruiting characteristics the avocado tree must produce new growth each year to remain productive (Whiley and Schaffer, 1994). However, if left unchecked the orchard eventually becomes crowded with a loss in yield and fruit quality.

The basic problem with overcrowded orchards is insufficient light (Stadler and Stassen, 1985). There are several systems to manage tree size and improve light interception and penetration, including tree thinning, stag-horning, selective limb removal and mechanical pruning. Significant advances have been made in the development of mechanised pruning and growth retardants in avocado orchards. However, recommendations on canopy management strategies for Australian growers have not yet been defined.

In South Africa, results indicate that mechanical pruning can be implemented without adversely affecting yields during the early stages of crowding (Stassen *et al*., 1999*a*). However in heavily crowded orchards, drastic pruning immediately after harvest resulted in no yield the following year. Several researchers have shown that a hedgerow system, with trees closer together in the row and with more space between rows, is the best way of improving light interception (Cain, 1972; Stadler and Stassen, 1985; Stassen and Davie, 1996). To ensure optimal light penetration a pyramidal shape is preferred with a tree height no greater than 80% of the row width (Stassen and Davie, 1996; Stassen *et al*. 1999*a*).

Triazoles, a group of plant growth retardants that inhibit gibberellin biosynthesis (Davis *et al*., 1988) have been reported to reduce vegetative growth and increase fruit size in avocado (Köhne and Kremer- Köhne, 1987; Köhne, 1988; Adato, 1990; Wolstenholme *et al*., 1990; Erasmus and Brooks, 1998; Penter *et al*., 2000; Whiley, 2001). Foliar application of uniconazole (Sunny®) at flowering to increase fruit size has been recently registered for the Australian avocado industry.

Trials were conducted to evaluate the effect of mechanical pruning and Sunny® on shoot growth, flowering, yield and fruit quality in 'Hass' avocado. This research was carried out in a warm subtropical climate in southeast Queensland (Childers/Bundaberg).

1.2 Materials and Methods

1.2.1 Experimental sites

In 2000/01, three experiments were established in Childers/Bundaberg to investigate the effect of pruning and Sunny® on shoot growth, flowering, yield and fruit quality in 'Hass' avocado. Trees were mechanically pruned at an angle of 15-20° from the vertical to form a pyramid following harvest in June-September and during summer following maturation of the spring growth flush in December-February. Foliar applications of 0.5 or 1% Sunny® were applied at mid-bloom and when regrowth following summer pruning reached a maximum of 100 mm. Trees were sprayed to the point of run-off using a motorised backpack spray unit (Stihl, Germany). Agral® a non-ionic wetter at 0.05% was included in all Sunny® applications.

1.2.2 Experiment 1 at Childers

1.2.2.1 Trees and treatments

In 2000/01, seven-year-old trees were pruned at an angle of 18° after harvest on the 15 June 2000. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 3 L per tree on the 14 September. Trees were left unpruned or pruned again on the 14 December or 19 January 2001. Sunny® at 3 L per tree was applied to the summer growth flush in trees not pruned during the summer on the 14 January. Regrowth in trees pruned in December and January was treated with Sunny® at 3.5 L per tree on the 9 January and the 19 February, respectively. There were 18 treatments with six trees per treatment. The treatments were:

Table 1 Pruning and Sunny® treatments on 'Hass' avocado at Childers (Experiment 1).

Treatments

No Sunny® at flowering

1. Pruned after harvest
2. Pruned after harvest + 0.5% Sunny® on summer growth
3. Pruned after harvest + 1% Sunny® on summer growth
4. Pruned after harvest and in December
5. Pruned after harvest and in December + 0.5% Sunny® on regrowth
6. Pruned after harvest and in December + 1% Sunny® on regrowth
7. Pruned after harvest and in January
8. Pruned after harvest and in January + 0.5% Sunny® on regrowth
9. Pruned after harvest and in January + 1% Sunny® on regrowth

1% Sunny® at flowering

10. Pruned after harvest
11. Pruned after harvest + 0.5% Sunny® on summer growth
12. Pruned after harvest + 1% Sunny® on summer growth
13. Pruned after harvest and in December
14. Pruned after harvest and in December + 0.5% Sunny® on regrowth
15. Pruned after harvest and in December + 1% Sunny® on regrowth
16. Pruned after harvest and in January
17. Pruned after harvest and in January + 0.5% Sunny® on regrowth
18. Pruned after harvest and in January + 1% Sunny® on regrowth

In 2001/02, trees were pruned at an angle of 18º after harvest on the 15 June. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 3 L per tree on the 13 September. Trees were left unpruned or pruned again on the 21 December or 19 January 2002. Sunny® at 3 L per tree was applied to the summer growth flush in trees not pruned during the summer on the 14 January. Regrowth in trees pruned in December and January was treated with Sunny® at 3 L per tree on the 28 January and the 22 February, respectively (Table 1).

The experiment was a split, split-plot design with 3 blocks with 6 main plots per block and 6 trees. The 6 main treatments were 2 spray treatments at flowering (no Sunny® and 1% Sunny®) by 3 pruning regimes (no summer pruning, December and January pruning) and were allocated to the 6 main plots in each block. The 3 Sunny® treatments applied to the summer growth (no Sunny®, 0.5% Sunny® and 1% Sunny®) were each applied to 2 trees in each main plot.

1.2.2.2 Fruit yield
In 2001 and 2002 trees were harvested by the 14 May and 11 June, respectively. The number and weight of fruit was recorded in six trees per treatment. Cumulative yields were calculated over the two years. In 2002, the harvest was split over 7 May, 21 May and 11 June.

1.2.2.3 Fruit quality
In 2001 and 2002, 40 and 20 mature fruit of uniform size were sampled from each tree from treatments 1, 4, 6 and 10, respectively (Table 1).

Fruit were dipped in Sportak® (prochloraz at 0.05% v/v) at the laboratory for 1 min within 4 h of harvest. In 2001 half the fruit were stored at 5°C for 4 weeks while the others were stored under simulated commercial conditions: 10°C for 3 days, 5°C for 5 days, 18°C + 10ppm ethylene for 3-4 days (until fruit had sprung) and 1°C for 4 days. In 2002 and 2003 fruit were stored only under commercial conditions. All fruit were ripened at 20°C and assessed for quality.

Fruit quality was assessed using the Avocare Quality Assessment Manual (White *et al*., 2001). External fruit quality was assessed after cold storage or ethylene treatment by recording the percentage of the skin surface area with discrete black patches (discrete skin patches, often caused by chilling) and the percentage of nodules with black colour (skin spotting, sometimes called lenticel damage). Fruit firmness was assessed using gentle hand pressure, and the days to ripe (DTR) determined as the number of days fruit were stored at 20°C until ripe. This corresponded to a firmness of 4-6 N when measured with an Instron Universal Testing Machine Model 1122 (Instron, High Wycombe, UK), fitted with an 8 mm hemispherical probe (probe penetration 2 mm).

Fruit were then longitudinally cut into quarters, the seed removed, and the skin peeled from the flesh. The quarters were visually rated for the severity of rots and internal disorders as the percentage of flesh volume affected. Body rots were characterised as those developing from the skin into the body of the fruit (caused mainly by the pathogen, *Colletotrichum gloeosporioides*), and stem-end rots as those starting from the stem-end of the fruit (caused by several pathogens, mainly *C. gloeosporioides* and *Dothiorella* spp.) (Coates *et al*., 1995). Diffuse discolouration was characterised as areas of grey or grey/brown discolouration with poorly defined margins (White *et al*., 2001) and vascular browning (ignoring discolouration associated with stem-end rots) was rated as the percentage of the flesh rendered non-useable by the disorder. The incidence or percentage of fruit affected with these rots and disorders were determined.

1.2.3 Experiment 2 at Childers

1.2.3.1 Trees and treatments

In 2000/01, six-year-old trees were pruned at an angle of 15° after harvest on the 11 September. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 2.25 L per tree for pruned trees or 3 L per tree for unpruned trees on the 25 September. Trees were left unpruned or pruned again in December, January or February. Sunny® was applied to the summer growth in trees not pruned during the summer at 2.25 L per tree on the 15 January 2001. Regrowth in trees pruned on the 18 December, 19 January or 19 February was treated with Sunny® at 2.25 L per tree on the 15 January, 19 February and 27 March, respectively. There were 12 treatments with six trees per treatment (Table 2).

Table 2 Pruning and Sunny® treatments on 'Hass' avocado at Childers (Experiment 2).

Treatments
1. Unpruned
2. Unpruned + 1% Sunny® at flowering
3. Unpruned + 1% Sunny® on summer growth
4. Pruned after harvest
5. Pruned after harvest + 1% Sunny® at flowering
6. Pruned after harvest + 1% Sunny® on summer growth
7. Pruned after harvest and in December
8. Pruned after harvest and in December + 1% Sunny® on regrowth
9. Pruned after harvest and in January
10. Pruned after harvest and in January + 1% Sunny® on regrowth
11. Pruned after harvest and in February
12. Pruned after harvest and in February + 1% Sunny® on regrowth

In 2001/02 trees were pruned at an angle of 15° after harvest on the 25 August. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 2.25 L per tree for pruned trees or 3 L per tree for unpruned trees on the 17 September. Trees were left unpruned or pruned again in December, January or February. Sunny® was applied to the summer growth in trees not pruned during the summer at 2.25 L per tree on the 18 January 2002. Regrowth in trees pruned on the 18 December, 18 January or 22 February was treated with Sunny® at 2.25 L per tree on the 18 January, 22 February and 25 March, respectively (Table 2).

The experiment was an unbalanced split-plot with 5 main plots per block and 4-6 trees (subplots) per main plot. The 5 pruning treatments (no pruning; pruned after harvest; pruned again in December; January; and February) were allocated to 5 main plots in each block. The 3 Sunny® treatments (no Sunny®; Sunny® at flowering; Sunny® on summer growth) were each applied to 2 trees in each of the no pruning and pruned after harvest main plots; whereas only 2 Sunny® treatments (no Sunny®, Sunny® on regrowth) were each applied to 2 trees in each of the prune again in December; January and February main plots.

1.2.3.2 Fruit yield

In 2001 and 2002 trees were harvested on the 3 July and 1 August, respectively. The number and weight of fruit was recorded in six trees per treatment. Cumulative yields were calculated over the two years.

1.2.3.3 Shoot growth and flowering

The effect of summer pruning and Sunny® application on shoot growth and flowering in 2000/01 and 2001/02 was assessed in 10 shoots in six trees for treatments 1, 3, 7-12 (Table 2). Shoots in unpruned trees were selected in December (after maturation of the spring growth flush), while in trees pruned in summer, shoots were tagged 4-6 weeks after pruning. The length of shoots and the number of shoots with floral buds were recorded prior to pruning in August.

1.2.3.4 Fruit quality

In 2001, 40 mature fruit were sampled from each tree from treatments 1, 4, 7 and 8 (Table 2). Half the fruit were stored at 5°C for 4 weeks while the others were stored under commercial conditions. In 2002, 20 mature fruit were sampled from each tree from treatments 1, 2, 4-8 (Table 2) and stored under commercial conditions. Fruit from both harvests were ripened at 20°C and assessed for quality as described earlier (section 1.2.2.3).

1.2.4 Experiment 3 at Goodwood

1.2.4.1 Trees and treatments

In 2000/01, five-year-old trees were left unpruned or pruned after harvest at an angle of 20° on the 10 August. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 2 L per tree for pruned trees and 2.5 L per tree for unpruned trees on the 15 September. Sunny® at 2.5 L per tree was applied to the summer growth on the 16 January to unpruned trees. Trees were left unpruned or pruned again on the 18 December, 19 January or 14 February. Regrowth in trees pruned in December, January and February received Sunny® at 2 L per tree on the 16 January, 14 February and 27 March, respectively. There were 20 treatments with six trees per treatment (Table 3).

Table 3 Pruning and Sunny® treatments on 'Hass' avocado at Goodwood (Experiment 3).

Treatments	
1.	Unpruned
2.	Unpruned + 1% Sunny® at flowering
3.	Unpruned + 0.5% Sunny® on summer growth
4.	Unpruned + 1% Sunny® on summer growth
5.	Pruned after harvest
6.	Pruned after harvest + 1% Sunny® at flowering
7.	Pruned after harvest + 0.5% Sunny® on summer growth
8.	Pruned after harvest + 1% Sunny® on summer growth
9.	Pruned after harvest and in December
10.	Pruned after harvest and in December + 1% Sunny® at flowering
11.	Pruned after harvest and in December + 0.5% Sunny® on regrowth
12.	Pruned after harvest and in December + 1% Sunny® on regrowth
13.	Pruned after harvest and in January
14.	Pruned after harvest and in January + 1% Sunny® at flowering
15.	Pruned after harvest and in January + 0.5% Sunny® on regrowth
16.	Pruned after harvest and in January + 1% Sunny® on regrowth
17.	Pruned after harvest and in February
18.	Pruned after harvest and in February + 1% Sunny® at flowering
19.	Pruned after harvest and in February + 0.5% Sunny® on regrowth
20.	Pruned after harvest and in February + 1% Sunny® on regrowth

In 2001/02, trees were left unpruned or pruned at an angle of 20º on the 2 August. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 2.25 L per tree for pruned trees and 2.5 L per tree for unpruned trees on the 12 September. Sunny® at 2.5 L per tree was applied to the summer growth on the 22 January to unpruned trees. Trees were left unpruned or pruned again on the 21 December, 22 January or 19 February. Regrowth in trees pruned in December, January and February received Sunny® at 2.25 L per tree on the 22 January, 19 February and 25 March, respectively (Table 3).

In 2002/03, trees were left unpruned or pruned at an angle of 20º on the 12 August. Trees were unsprayed or sprayed with 1% Sunny® at flowering at 1.5 L per tree for pruned trees and 2 L per tree for unpruned trees on the 12 September. Sunny® at 2 L per tree was applied to the summer growth on the 9 January to unpruned trees. Trees were either left unpruned or pruned again on the 10 December, 17 January or 17 February. Regrowth in trees pruned in December, January and February received Sunny® at 1.5 L per tree on the 9 January, 24 February and 25 March, respectively (Table 3) .

The experiment was a split-plot with 3 blocks with 5 main plots per block and 8 trees (subplots) for each main plot. The 5 pruning treatments (unpruned, pruned after harvest, pruned again in December; January; and February) were allocated to the 5 main plots in each block. The 4 Sunny® treatments (no Sunny®; 1% Sunny® at flowering; 0.5% Sunny® or 1% Sunny® on summer growth) were each applied to 2 trees in each plot.

1.2.4.2 Fruit yield

In 2001, 2002 and 2003, trees were harvested by the 12 June, 17 June and 5 August, respectively and the number and weight of fruit recorded on six trees per treatment. Cumulative yields were calculated over the three years. In 2002 and 2003, fruit was harvested separately from ground level to 2 m high (bottom) and from 2 m to the tops of trees (top).

1.2.4.3 Shoot growth and flowering

The effect of summer pruning and Sunny® on shoot growth and flowering was assessed over three years in 10 shoots in six trees from treatments 1, 3, 4, 9, 11-13, 15-17, 19 and 20 (Table 3) as described in section 1.2.3.3.

1.2.4.4 Fruit quality

In 2002 and 2003, 20 mature fruit were sampled from each tree from treatments 1, 2, 5, 6, 9 and 12 (Table 3). Fruit were stored under commercial conditions and assessed for quality as described in section 1.2.2.3.

1.2.5 Statistical analysis

The experimental design used varied according to the treatments being tested and data was analysed by ANOVA. The least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means. Skewed data were angular transformed before analysis and the back-transform data are presented. In Experiment 2, data was analysed by residual maximum likelihood.

1.3 Results

1.3.1 Experiment 1 at Childers

1.3.1.1 Fruit yield

There was no significant ($P > 0.05$) effect of summer pruning or Sunny® on yield, number of fruit in both years, or on cumulative yield (Tables 4 and 5). However, 1% Sunny® at flowering increased average fruit weight in both years compared with untreated trees.

In 2002, the largest fruit were picked first to allow the remaining fruit to grow. Sunny® at flowering increased, while pruning in January reduced the percentage of the fruit harvested in the first harvest relative to total fruit yield (Table 6).

Table 4 Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Childers (Experiment 1) in 2000/01. Pruning and Sunny® data are means of 36 and 18 trees, respectively. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)
Pruning				
No summer	105.5a	19.5a	405a	262a
December	100.9a	18.7a	392a	258a
January	102.2a	18.9a	397a	259a
Sunny®				
Nil	103.6a	19.2a	418a	248b
0.5% on regrowth	100.2a	18.5a	401a	250b
1% on regrowth	99.1a	18.3a	390a	255b
1% at flowering	98.1a	18.2a	361a	273a
1% at flowering + 0.5% on regrowth	108.9a	20.1a	412a	265a
1% at flowering + 1% on regrowth	107.3a	19.9a	403a	266a

*t/ha was calculated from the tree spacing of 9 x 6 m (185 trees/ha).

Table 5 Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Childers (Experiment 1) in 2001/02 and cumulative yields for the 2001 and 2002. Pruning and Sunny® data are means of 36 and 18 trees, respectively. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)	Cumulative yield (kg/tree)	Cumulative yield (t/ha*)
Pruning						
No summer	80.2a	14.8a	353a	229a	185.9a	34.4a
December	73.4a	13.6a	332a	222b	174.2a	32.2a
January	70.9a	13.1a	330a	216b	173.1a	32.0a
Sunny®						
Nil	77.8a	14.4a	364a	214b	181.3a	33.5a
0.5% on regrowth	71.3a	13.2a	334a	214b	171.4a	31.7a
1% on regrowth	73.3a	13.6a	344a	212b	172.4a	31.9a
1% at flowering	73.5a	13.6a	322a	231a	171.6a	31.8a
1% at flowering + 0.5% on regrowth	77.1a	14.3a	335a	231a	186.0a	34.4a
1% at flowering + 1% on regrowth	76.0a	14.1a	329a	232a	183.3a	33.9a

*t/ha was calculated from the tree spacing of 9 x 6 m (185 trees/ha).

Table 6 Effects of pruning and Sunny® on the percentage of total yield of 'Hass' avocado harvested on the 7 May, 21 May and 11 June at Childers (Experiment 1) in 2001/02. Pruning and Sunny® data are means of 36 and 18 trees, respectively. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Harvest 1	Harvest 2	Harvest 3
Pruning			
No summer	32.1a	16.9a	51.0b
December	29.2a	16.0a	54.8ab
January	22.8b	16.4a	60.8a
Sunny®			
Nil	21.3b	13.4a	65.3a
0.5% on regrowth	18.7b	16.1a	65.2a
1% on regrowth	19.9b	16.3a	63.9a
1% at flowering	37.5a	16.6a	45.9b
1% at flowering + 0.5% on regrowth	33.1a	19.1a	47.9b
1% at flowering + 1% on regrowth	37.8a	17.2a	45.0b

1.3.1.2 Fruit quality

In 2000/01 there was no significant effect of Sunny® application or additional pruning in December on the severity and incidence of rots and disorders in fruit stored at 5°C for four weeks, or under simulated commercial conditions (data not presented).

In 2001/02, the severity of body rots was greater in trees pruned after harvest and in December than those pruned after harvest only (Table 7). Sunny® had no significant effect on body rots. There were no treatment effects on other fruit defects.

Table 7 2001/02. Effects of pruning and Sunny® on the severity of body rots (percentage of flesh volume affected) in 'Hass' avocado fruit stored under commercial conditions and ripened at 20ºC. Data are means of 120 fruit from six trees per treatment. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Body rots (% of flesh affected)
Pruned after harvest	6.02b
Pruned after harvest + 1% Sunny at flowering	5.98b
Pruned after harvest and in December	8.25a
Pruned after harvest and in December + 1% Sunny® on regrowth	7.26ab

1.3.2 Experiment 2 at Childers

1.3.2.1 Fruit yield

Pruning after harvest reduced yield and fruit number compared with unpruned trees in 2000/01 (Table 8). There was no effect of additional pruning in summer or Sunny® application on yield. The reduced yield was mostly due to reduced fruit number. Average fruit weight was increased with pruning after harvest and Sunny® at flowering, but this did not compensate for the reduced fruit number in these treatments.

In 2001/02, trees pruned after harvest had similar yield to the non-pruned trees (Table 9), most likely because of the lower yields in the non-pruned trees in 2001/02 compared with 2000/01. However, yield was reduced when the trees were pruned again in February. Average fruit weight was greatest with Sunny® applied at flowering, and especially with pruning after harvest. Cumulative yield over the two seasons was highest with no pruning and Sunny® at flowering. Again, fruit number per tree was the major factor contributing to the reduced yield in February-pruned trees.

Table 8 Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Childers (Experiment 2) in 2000/01. Data are means of six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit /tree	Av. fruit wt. (g)
Unpruned	70.2a	23.4a	342a	206de
Unpruned + 1% Sunny® at flowering	62.3ab	20.7ab	270abc	230bc
Unpruned + 1% Sunny® on summer growth	56.3abc	18.7abc	284ab	201e
Pruned after harvest	30.7d	10.2d	131e	247b
Pruned after harvest + 1% Sunny® at flowering	40.5cd	13.5cd	157de	267a
Pruned after harvest + 1% Sunny® on summer growth	41.6cd	13.8cd	186cde	226c
Pruned after harvest and in December	31.1d	10.4d	136e	232bc
Pruned after harvest and in December + 1% Sunny® on regrowth	31.4d	10.5d	145de	219cde
Pruned after harvest and in January	48.2bcd	16.0bcd	232bcd	214cde
Pruned after harvest and in January + 1% Sunny® on regrowth	45.3bcd	15.1bcd	212bcde	219cde
Pruned after harvest and in February	35.0d	11.7d	158de	224cd
Pruned after harvest and in February + 1% Sunny® on regrowth	38.2cd	12.7cd	173de	223cd

*t/ha was calculated from the tree spacing of 5 x 6 m (333 trees/ha).

Table 9 Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Childers (Experiment 2) in 2001/02 and cumulative yields for 2001 and 2002. Data are means of six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Yield		Cumulative yield		Fruit no.	Av. fruit
	(kg/tree)	(t/ha*)	(kg/tree)	(t/ha*)	/tree	***wt.*** (g)
Unpruned	44.8ab	14.9ab	115.0a	38.3a	236a	192cde
Unpruned + 1% Sunny® at flowering	46.3a	15.4a	108.6a	36.1a	211ab	222ab
Unpruned + 1% Sunny® on summer growth	38.6abc	12.9abc	94.9ab	31.6ab	215ab	182e
Pruned after harvest	44.7ab	14.9ab	75.4bcd	25.1bcd	226ab	201cd
Pruned after harvest + 1% Sunny at flowering	39.0abc	13.0abc	79.5bcd	26.5bcd	171abc	228a
Pruned after harvest + 1% Sunny® on summer growth	40.9abc	13.6abc	82.5bc	27.4bc	226ab	183de
Pruned after harvest and in December	31.4abcd	10.5abcd	62.5cd	20.9cd	156abc	204bc
Pruned after harvest and in December + 1% Sunny® on regrowth	31.0bcd	10.3bcd	62.4cd	20.8cd	159abc	199cde
Pruned after harvest and in January	30.3bcd	10.1bcd	78.5bcd	26.1bcd	152abc	204bc
Pruned after harvest and in January + 1% Sunny® on regrowth	29.1cd	9.7cd	74.4bcd	24.8bcd	148bc	202c
Pruned after harvest and in February	22.3d	7.4d	57.3d	19.1d	123c	188cde
Pruned after harvest and in February + 1% Sunny® on regrowth	27.8cd	9.3cd	66.0cd	21.9cd	145bc	197cde

*t/ha was calculated from the tree spacing of 5 x 6 m (333 trees/ha)

1.3.2.2 Shoot growth and flowering

In both years, pruning increased new shoot length compared with no pruning (Table 10). December pruning resulted in the greatest shoot length, and Sunny® reduced shoot length in all the pruning treatments, The timing of the summer pruning also influenced flowering the following spring. Flowering was least in trees pruned in February, and Sunny increased flowering in the January and February pruning treatments.

Table 10 Effects of pruning and Sunny® on shoot growth and flowering in 'Hass' avocado at Childers (Experiment 2) in 2000/01and 2001/02. Data are means of 60 shoots from six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	2000/01		2001/02	
	Shoot length (cm)	Flowering (% of shoots)	Shoot length (cm)	Flowering (% of shoots)
Unpruned	21.8ef	88.3ab	19.6de	91.7ab
Unpruned + 1% Sunny® on summer growth flush	17.5f	93.3a	16.0f	95.0a
Pruned after harvest and in December	47.9a	78.3bc	37.1a	85.0bc
Pruned after harvest and in December + 1% Sunny® on regrowth	30.0cd	91.7ab	26.4c	91.7ab
Pruned after harvest and in January	36.1b	55.0de	29.8b	75.0d
Pruned after harvest and in January + 1% Sunny® on regrowth	25.6de	75.0c	22.4d	86.7abc
Pruned after harvest and in February	35.5bc	43.3e	27.5bc	65.0e
Pruned after harvest and in February + 1% Sunny® on regrowth	26.2de	66.7cd	19.1e	78.3cd

1.3.2.3 Fruit quality

In 2000/01, pruning after harvest and pruning after harvest and again in December (without Sunny®) increased the severity of skin spotting and diffuse discolouration of the flesh in fruit stored at 5ºC for 4 weeks compared with unpruned trees (Fig. 2). Pruning after harvest and pruning after harvest and in December ± Sunny® also increased discrete patches on the skin. The three pruning/Sunny® treatments also had a higher incidence of spotting and discrete patches on the skin (Fig. 3). However, Sunny® reduced skin spotting and diffuse discolouration severity to levels similar to non-pruned treatments (Fig. 2).

Pruning after harvest or after harvest and in December increased the severity and incidence of diffuse discolouration in fruit stored under simulated commercial conditions compared with unpruned trees (Table 11). Sunny® again reduced severity and incidence to levels statistically similar to no pruning.

There was no effect of pruning and Sunny® on the incidence of fruit rots.

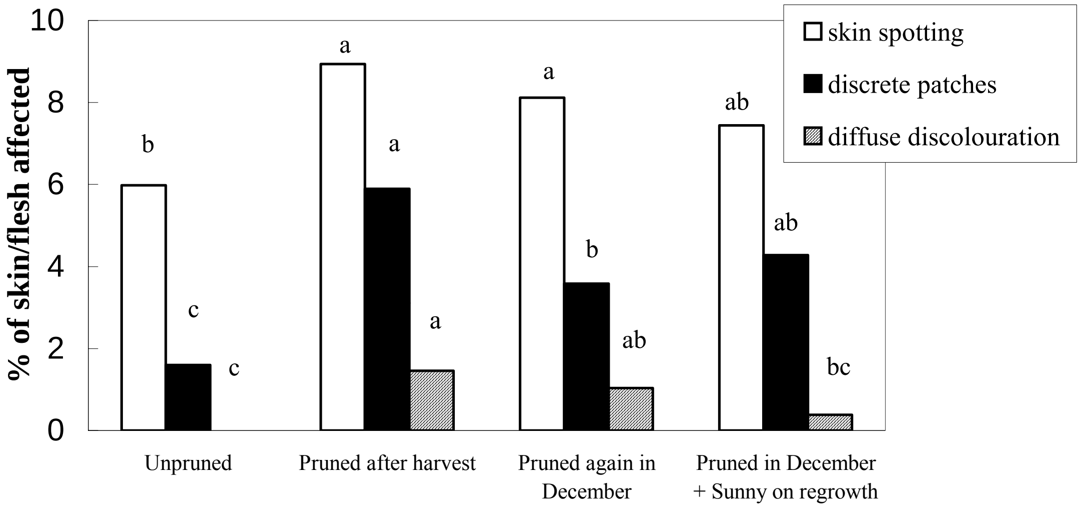

Fig. 2 2000/01. Effects of pruning and Sunny® on the severity of spotting and discrete patches on the skin and diffuse discolouration of the flesh in fruit stored at 5ºC for four weeks. Values are the means of 120 fruit from six trees per treatment. Means with the same letters are not significantly different ($P > 0.05$).

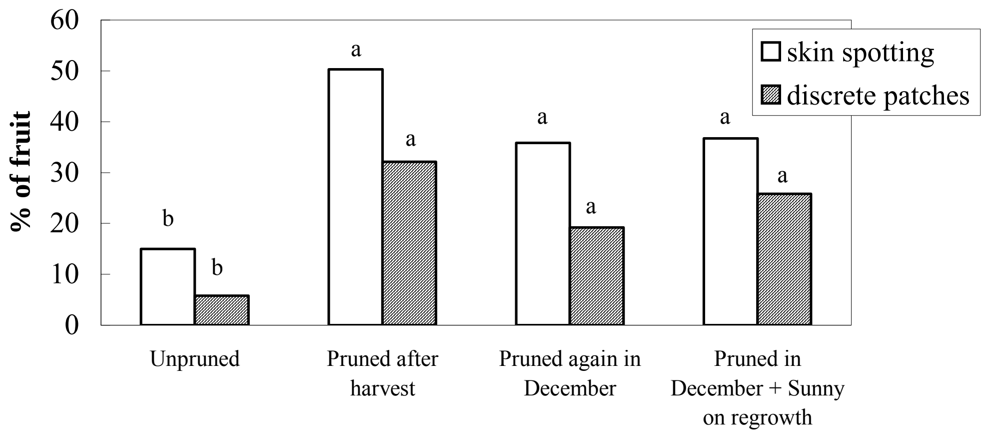

Fig. 3 2000/01. Effects of pruning and Sunny® on the incidence of spotting and discrete patches on the skin in fruit stored at 5ºC for four weeks. Values are the means of 120 fruit from six trees per treatment. Means with the same letters are not significantly different ($P > 0.05$).

Table 11 2000/01. Effects of pruning and Sunny® on the severity and incidence of diffuse discolouration in 'Hass' fruit stored under commercial conditions and ripened at 20ºC. Data are means of 120 fruit from six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Diffuse discolouration	
	Severity (% of flesh)	Incidence (% of fruit)
Unpruned	0.50b	5.8b
Pruned after harvest	2.67a	40.6a
Pruned after harvest and in December	3.67a	35.8a
Pruned after harvest and in December + 1% Sunny® on regrowth	2.42ab	26.7ab

In 2001/02, body rots and diffuse discolouration severity was again greater in the trees pruned after harvest and again in December compared with the non-pruned trees (Fig. 4). Stem-end rots were higher in trees pruned after harvest. Sunny® reduced these defects to levels similar to the non-pruned treatments.

There was no effect of pruning and Sunny® on the incidence of fruit disorders.

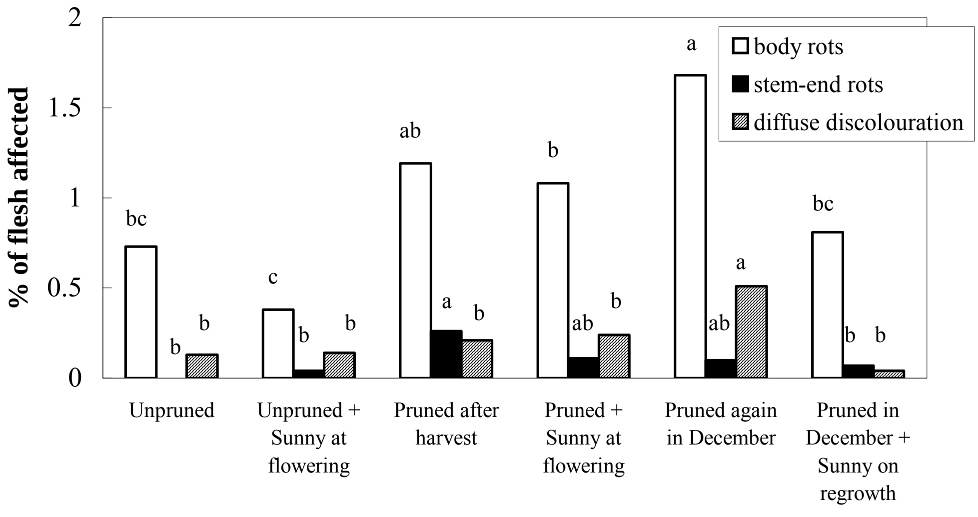

Fig. 4 2001/02. Effect of pruning and Sunny® application on the severity of body and stem-end rots and diffuse discolouration of the flesh in fruit stored under commercial conditions and ripened at 20ºC. Values are the means of 120 fruit from six trees per treatment. Means with the same letters are not significantly different ($P > 0.05$).

1.3.3 Experiment 3 at Goodwood

1.3.3.1 Fruit yield

In 2000/01 and 2001/02, pruning reduced yield and fruit number compared with non-pruned trees (Tables 12 and 13). Pruning in January resulted in lower yields than pruning in December in both years, and pruning in February resulted in the lowest yields in 2001/02 but not in 2000/01. Average fruit weight was also greater in those trees pruned again in February compared with unpruned trees.

In 2002/03, there was no effect of pruning after harvest on yield or fruit number compared with unpruned trees, except where pruning after harvest and in January reduced yield compared with control (Table 14). Cumulative yields over the three years were highest in the unpruned trees and lowest with pruning in January and February (Table 14).

1% Sunny® at flowering increased fruit yield in 2001/02, with similar trends in the other years. 2001/02 also had the lowest yields of the three years. In all treatment years Sunny® increased average fruit weight. Sunny treatment of the regrowth did not affect fruit size or yield in any of the treatment years compared with no Sunny®. Sunny® at flowering also increased cumulative yields over the three years, but treatment of the regrowth had not effect ton yield.

Pruning also increased the number of fruit harvested in the lower section of the tree (Table 15). There was no effect of Sunny® on fruit distribution within the tree.

Table 12 2000/01. Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Goodwood (Experiment 3). Pruning and Sunny® data are means of 24 and 30 trees, respectively. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)
Pruning				
Unpruned	125.8a	25.2a	557a	228bc
Pruned after harvest	88.7bc	17.7bc	400bc	225c
Pruned after harvest and in December	94.0b	18.8b	417b	226c
Pruned after harvest and in January	76.3c	15.3c	330c	233b
Pruned after harvest and in February	101.6b	20.3b	429b	240a
Sunny®				
Nil	97.5a	19.5a	443a	223b
1% at flowering	101.8a	20.4a	403a	254a
0.5% on growth	96.3a	19.3a	439a	220b
1% on growth	93.6a	18.7a	422a	224b

*t/ha was calculated from the tree spacing of 10 x 5 m (200 trees/ha).

Table 13 2001/02. Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Goodwood (Experiment 3). Pruning and Sunny® data are means of 24 and 30 trees, respectively. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)
Pruning				
Unpruned	99.8a	20.0a	544a	185d
Pruned after harvest	63.3b	12.7b	319b	199c
Pruned after harvest and in December	67.2b	13.5b	338b	201c
Pruned after harvest and in January	48.0c	9.6c	233c	209b
Pruned after harvest and in February	33.5d	6.7d	155d	217a
Sunny®				
Nil	60.7b	12.1b	309a	200b
1% at flowering	70.3a	14.1a	334a	218a
0.5% on growth	58.1b	11.6b	310a	195b
1% on growth	60.4b	12.1b	319a	197b

*t/ha was calculated from the tree spacing of 10 x 5 m (200 trees/ha).

Table 14 2002/03. Effects of pruning and Sunny® on 'Hass' avocado yield, number of fruit and average fruit weight at Goodwood (Experiment 3), and cumulative yield in 2001 to 2003. Pruning and Sunny® data are means of 24 and 30 trees, respectively. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)	Cumulative yield (kg/tree)	Cumulative yield (t/ha*)
Pruning						
Unpruned	124.8ab	25.0ab	708a	178a	350.5a	70.1a
Pruned after harvest	137.8a	27.5a	737a	188a	289.6b	57.9b
Pruned after harvest and in December	128.5ab	25.7ab	669a	192a	289.7b	57.9b
Pruned after harvest and in January	108.3c	21.7c	580a	189a	253.7c	46.5c
Pruned after harvest and in February	118.6bc	23.7bc	621a	192a	232.7c	50.7c
Sunny®						
Nil	120.7a	24.1a	661a	184b	278.9b	55.8b
1% at flowering	128.3a	25.7a	655a	197a	300.4a	60.1a
0.5% on growth	123.2a	24.6a	669a	185b	277.6b	55.5b
1% on growth	122.1a	24.4a	667a	185b	276.0b	55.2b

*t/ha was calculated from the tree spacing of 10 x 5 m (200 trees/ha).

Table 15 Effects of pruning and Sunny® on fruit distribution of 'Hass' avocado at Goodwood (Experiment 3) in 2002 and 2003. The percentage of the total number of fruit harvested from the lower section (ground level to 2 m high) of the tree is presented. Pruning and Sunny® data are means of 24 and 30 trees, respectively. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Percentage of fruit at 0-2 m height	
	2002	2003
Pruning		
Unpruned	28.7d	12.0b
Pruned after harvest	42.1c	20.9a
Pruned after harvest and in December	49.7b	19.8a
Pruned after harvest and in January	50.7ab	21.4a
Pruned after harvest and in February	54.9a	23.1a
Sunny®		
Nil	42.9a	19.3a
1% at flowering	44.7a	19.9a
0.5% on growth	46.6a	18.8a
1% on growth	46.8a	19.8a

1.3.3.2 Shoot growth and flowering

All pruning treatments increased shoot growth and reduced flowering compared with no pruning (Tables 16 and 17). The timing of the summer pruning also affected regrowth and flowering, with highest shoot growth with December pruning, and the lowest flowering with February pruning. Sunny® at 0.5 and 1% reduced regrowth and increased flowering.

Table 16 Effects of pruning and Sunny® on shoot growth (cm) in 'Hass' avocado at Goodwood (Experiment 3) in 2000/01, 2001/02 and 2002/03. Pruning and Sunny® data are means of 18 and 24 trees, respectively. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Shoot growth (cm)		
	2000/01	2001/02	2002/03
Pruning			
Unpruned	26.0c	27.9b	19.0c
Pruned after harvest and in December	45.5a	30.2a	41.3a
Pruned after harvest and in January	36.0b	21.3d	22.5b
Pruned after harvest and in February	36.8b	22.4c	19.5c
Sunny®			
Nil	43.7a	31.1a	31.7a
0.5% on growth	33.1b	22.3b	22.5b
1% on growth	31.4b	23.0b	22.5b

Table 17 Effects of pruning and Sunny® on shoot flowering (%) in 'Hass' avocado at Goodwood (Experiment 3) in 2000/01, 2001/02 and 2002/03. Pruning and Sunny® data are means of 18 and 24 trees, respectively. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	2000/01	2001/02	2002/03
Pruning			
Unpruned	87.2a	96.7a	92.8a
Pruned after harvest and in December	75.6b	91.7b	78.3b
Pruned after harvest and in January	75.6b	87.2c	76.1b
Pruned after harvest and in February	50.6c	72.2d	43.9c
Sunny®			
Nil	63.3b	77.9b	54.6b
0.5% on growth	75.8a	90.8a	79.2a
1% on growth	77.5a	92.1a	84.6a

1.3.3.3 Fruit quality

In 2001/02, pruning after harvest only, increased the severity of vascular browning compared with non-pruned trees, but Sunny® applied to this treatment reduced vascular browning to levels similar to the non-pruned trees (Table 18). However, the severity of this disorder was low with less than 1% of the flesh affected. There was no effect of pruning or Sunny® on the incidence of fruit rots and disorders.

In 2002/03 there was no effect of pruning or Sunny® on the severity and incidence of fruit rots and disorders.

Table 18 2001/02. Effects of pruning and Sunny® on the severity (percentage of flesh affected) of vascular browning in 'Hass' avocado fruit stored under simulated commercial conditions and ripened at 20ºC. Data are means of 120 fruit from six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Vascular browning severity (%)
Unpruned	0.15b
Unpruned + 1% Sunny® at flowering	0.15b
Pruned after harvest	0.58a
Pruned after harvest + 1% Sunny® at flowering	0.34ab
Pruned after harvest and in December	0.09b
Pruned after harvest and in December + 1% Sunny® on regrowth	0.15b

1.4 Discussion

The results of these trials indicate that pruning can reduce yield in trees pruned for the first time. However, after 2-3 years the difference in yield between pruned and non-pruned trees was less. A considerable amount of growth was removed (2-2.5 m) in the first year compared with 1 m in subsequent years. Penter and Snijder (2001) found trees pruned for the first time had a negative effect on yield due to removal of large branches. However there was no significant effect of pruning on yield in the second year. Stassen *et al*. (1999*a*) showed that orchards in the initial stages of crowding can be selectively or mechanically pruned without adversely affecting yields. In heavily crowded orchards, drastic pruning immediately after harvest resulted in no yield the following year.

Trees should be pruned after harvest and before flowering to minimise yield losses due to removal of inflorescences. In Experiment 1, trees were harvested in May and pruned on the 15 June. In 2000 prior to pruning, mean yield was 14 t/ha and this increased to 19 t/ha in 2001 despite the removal of 2-2.5 m of growth in June 2000. In Experiment 2, trees were harvested in August 2000 and pruned in early September when inflorescences were already at the cauliflower stage. Pruned trees yielded 10 t/ha compared with 23 t/ha for unpruned trees. Stassen (1999) suggests trees that have borne a crop should be pruned as soon as possible after harvest. Trees pruned too late in the winter do not have sufficient time for bearer shoots to harden off and many flower buds that have initiated will be pruned away.

Stassen *et al*. (1999*b*) suggest that pruning is not a one-off operation and follow-up summer pruning is required. Summer pruning is dependent on establishing and maintaining the tree shape established before fruit set so that mechanical pruning can be implemented in the presence of the crop. The timing of the summer prune influences the length of regrowth and ultimate increase in tree size. Pruning in mid to late summer in southeast Queensland reduced flowering the following spring and subsequent yield. In Experiment 2 in 2000/01, 55 and 43% of the shoots flowered in trees pruned in January and February, respectively compared with 88% in unpruned trees. Application of Sunny® to regrowth resulting from summer pruning reduced regrowth length and increased flowering in these shoots to 75 and 67% in trees pruned in January and February.

Competition between rapidly expanding spring growth flush leaves and setting fruitlets have been shown to reduce fruit set in avocado (Biran, 1979; Blumenfeld *et al*., 1983) Application of Sunny® at mid-bloom has been reported to increase fruit size and yield (Erasmus and Brooks, 1998; Penter *et al*., 2000; Whiley, 2001). In our experiments Sunny® at flowering consistently increased fruit size by 7-16%. Application of Sunny® at mid-bloom has also been reported to improve fruit quality by reducing flesh discolouration in 'Hass' following storage of fruit at 5ºC for 4 weeks (Whiley, 2001). However, there was no effect of Sunny® at flowering on fruit quality in the current trials.

These trials indicate that pruning after harvest reduces yield when pruned for the first time, however this negative effect decreases in subsequent years. Pruning time is critical in determining the success of canopy management. In subtropical southeast Queensland pruning soon after harvest may induce vegetative growth that may compete with the developing fruit and reduce fruit quality. Therefore, further trials on the timing of post-harvest pruning are required before recommendations can be made.

In relation to summer pruning, timing is also critical, since it determines whether the new shoots are sufficiently mature to flower the following spring. Thus, February pruning reduced flowering and yield, while December and January pruning had less effect on yield. Treatment of the summer regrowth with Sunny® can reduce this negative effect on flowering.

2 Effects of time of pruning after harvest on growth, yield and fruit quality in 'Hass' avocado in southeast Queensland

2.1 Introduction

Previous work on mechanical pruning on 'Hass' avocado in the subtropical southeast Queensland identified that pruning stimulated vegetative growth and the amount of regrowth at flowering and early fruit set can affect fruit quality. Orchards pruned soon after harvest had more growth (20-30 cm) present during flowering than those pruned one-two months later (< 5 cm). More fruit rots and disorders were observed in trees pruned soon after harvest. A study was conducted to determine the effect of pruning time after harvest on growth, yield and fruit quality in 'Hass' avocado.

2.2 Materials and Methods

2.2.1 Experimental site and trees

The experiment was conducted in a commercial orchard near Bundaberg (lat. 25ºS) on 7-year-old 'Hass' avocado trees. Trees were left unpruned or pruned immediately after harvest (17 June 2002), or one (11 July) or two months (13 August) later. Dormant shoots were present in June, floral buds in July and floral buds at the shoot tip and in leaf axes in August. Trees were pruned by hand at an angle of 20° from the vertical to form a pyramid.

2.2.2 Shoot growth and yield

Growth was measured on 20 shoots in each tree at early fruit set (7 October 2002) and at harvest (5 August 2003). The number and weight of fruit harvested at maturity was recorded in six trees per treatment and the average fruit weight calculated.

2.2.3 Fruit quality

Twenty mature fruit were harvested from each tree, stored under simulated commercial conditions and assessed for quality as described in section 1.2.2.3.

2.2.4 Statistical analysis

Experimental treatments were replicated six times in a completely randomised design using single tree plots. Statistical analyses were by ANOVA and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means. Skewed data were angular transformed before analysis and back-transformed data is presented.

2.3 Results

2.3.1 Shoot growth and yield

Trees pruned immediately after harvest had longer shoots than unpruned trees or those pruned later, while pruning 1-2 months after harvest resulted in similar shoot length to the non-pruned trees (Table 19). However, all pruned trees had lower yields due to lower fruit numbers, despite increased fruit weight. There was no effect of pruning time on yield or fruit weight.

Table 19 Effects of time of after-harvest pruning on yield, number of fruit, average fruit weight and shoot growth in 'Hass' avocado at Goodwood in 2002/03. Data are the means of six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Yield		No. of	Av. fruit	Shoot growth	
	(kg/tree)	(t/ha*)	fruit/tree	wt. (g)	7/10/02	5/08/03
Unpruned	129.8a	26.0a	738a	180b	4b	17b
Pruned immediately after harvest	91.5b	18.3b	453b	203a	15a	31a
Pruned one month after harvest	97.4b	19.5b	478b	205a	8b	22b
Pruned two months after harvest	98.3b	19.7b	507b	197a	6b	20b

t/ha was calculated from the tree spacing of 10 x 5 m (200 trees/ha).

2.3.2 Fruit quality

Trees pruned immediately after harvest or one month later had a higher incidence of fruit body rots compared with unpruned trees (Table 20). There was no difference in incidence between the non-pruned trees and those pruned two months after harvest.

There were no treatment effects on other fruit rots of disorders.

Table 20 Effects of after-harvest pruning and Sunny® on the incidence of body rots in 'Hass' avocado fruit from Goodwood in 2002/03 that were stored under simulated commercial conditions and ripened at 20ºC. Data are means of 120 fruit from six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Body rots incidence (% of fruit affected)
Unpruned	8.27c
Pruned immediately after harvest	40.6a
Pruned one month after harvest	27.5ab
Pruned two months after harvest	18.8bc

2.4 Discussion

The results of this trial again confirm that pruning reduces yield. While the timing does not affect yield, it can affect fruit quality. In the warmer production areas of southeast Queensland (where the harvest is completed in winter prior to flowering in spring) pruning soon after harvest can induce more vegetative growth compared to later pruning. This increased growth competes with the developing fruit, and is the most likely cause for the increased rots in the early pruned trees. Similar effects of competing vegetative growth reducing fruit quality have been reported previously (Cutting and Bower, 1990), and is the likely mechanism of Sunny® improving fruit quality (Whiley, 2001).

3. Effects of pruning on growth, yield and fruit quality in 'Shepard' avocado in north Queensland

3.1 Introduction

'Shepard', a Mexican x Guatemalan hybrid is the earliest maturing commercial cultivar grown in Australia. It is sensitive to cool temperatures during flowering and is grown on the Atherton Tableland in north Queensland and in the Childers/Bundaberg region in southeast Queensland. In north Queensland harvesting is often completed in March with several growers pruning the trees soon after. However, pruning at this time can induce significant regrowth that can reduce yield and fruit quality.

Trials were conducted to evaluate the effect of pruning time on shoot growth, yield and fruit quality on 'Shepard' avocado in Mareeba. Sunny® at flowering and to regrowth following pruning were applied to reduce the vegetative:reproductive competition.

3.2 Materials and Methods

The experiments were carried out on 'Shepard' avocado grown in a commercial orchard in Mareeba (lat., 17ºS).

3.2.1 Experiment 1

In 2002/03, three-year-old trees were left unpruned or pruned either immediately after harvest (28 March 2002) or one (29 April) or two months (3 June) later. Floral buds were present in trees pruned in June. Trees were pruned by hand at an angle of 18° from the vertical to form a pyramid. Experimental treatments were replicated five times in a randomised block design using single tree plots. Growth in 10 shoots in each tree and the number and weight of fruit was recorded on the 6 March 2003.

3.2.2 Experiment 2

In 2003/04, four-year-old trees were either left unpruned or pruned immediately after harvest (3 March), and when floral buds were present (2 July). Trees were pruned by hand at an angle of 18° from the vertical to form a pyramid. Sunny® (1.7 L per tree) was applied at flowering and to the regrowth following pruning. Trees were sprayed to the point of run-off using a motorised, backpack spray unit (Stihl, Germany). Regrowth in pruned trees was left unsprayed or sprayed with 1% Sunny® on 22 May. Unpruned trees were unsprayed or received 0.5 or 1% Sunny® at flowering on 30 July. Regrowth in trees pruned on 2 July was also treated with 1% Sunny® on 30 July. Trees that received 0.5% Sunny® at flowering were retreated 21 days later. There were seven experimental treatments which were replicated six times in a randomised block design using single tree plots (Table 21).

Table 21 Pruning and Sunny® treatments on 'Shepard' avocado at Mareeba (Experiment 2).

Treatments
1. Unpruned
2. Unpruned + 0.5% Sunny® at flowering and 21 days later
3. Unpruned + 1% Sunny® at flowering
4. Pruned after immediately after harvest
5. Pruned after immediately after harvest + 1% Sunny® on regrowth
6. Pruned when floral buds present
7. Pruned when floral buds present + 1% Sunny® on regrowth

The number and weight of fruit was recorded in six trees per treatment on the 23 March 2004. Twenty mature fruit were sampled from each tree from treatments 1, 3-7, ripened at 20°C and assessed for quality as described earlier (section 1.2.2.3).

3.2.3. Statistical analysis

Statistical analyses were by ANOVA and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means.

3.3 Results

3.3.1 Experiment 1

Pruning immediately after harvest decreased yield and fruit number compared with non-pruned trees but pruning one and two months after harvest produced similar yields to no pruning (Table 22). There was no effect on fruit weight.

The pruned trees had longer shoots than the controls, with the trees pruned immediately after harvest having the longest shoots.

Table 22 2002/03. Effects of pruning on yield, number of fruit, average fruit weight and shoot growth in 'Shepard' avocado at Mareeba (Experiment 1). Data are the means of five trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)	Shoot length (cm)
Unpruned	38.0a	6.4a	170a	226a	45c
Pruned immediately after harvest	17.6b	2.9b	76b	235a	81a
Pruned one month after harvest	30.4ab	5.1ab	134ab	231a	73ab
Pruned two months after harvest	41.5a	6.9a	190a	222a	66b

***** t/ha was calculated from the tree spacing of 10 x 6 m (167 trees/ha).

3.3.2 Experiment 2

Pruning decreased yield and fruit number compared with non-pruned trees, with no benefit of Sunny® to pruned or non-pruned trees (Table 23). There was no treatment effect on average fruit weight.

There was no significant effect of pruning or Sunny® on the severity and incidence of fruit rots and disorders.

Table 23 2003/04. Effects of pruning and Sunny® on yield, number of fruit and average fruit weight in 'Shepard' avocado at Mareeba (Experiment 2). Data are the means of six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit /tree	Av. fruit wt. (g)
Unpruned	72.8a	12.2a	317a	231a
Unpruned + 0.5% Sunny® at flowering and 21 days later	69.8ab	11.7ab	284ab	246a
Unpruned + 1% Sunny® at flowering	67.6ab	11.3ab	283ab	242a
Pruned immediately after harvest	43.8c	7.3c	185c	239a
Pruned immediately after harvest + 1% Sunny® on regrowth	57.5bc	9.6bc	248bc	233a
Pruned when floral buds present	49.8c	8.3c	212c	235a
Pruned when floral buds present + 1% Sunny® on regrowth	51.3c	8.6c	213c	242a

*t/ha was calculated from the tree spacing of 10 x 6 m (167 trees/ha).

3.4 Discussion

These trials demonstrate that pruning immediately after harvest reduces yield and increases vegetative growth in 'Shepard' avocado. In north Queensland, harvesting is often completed in March and several growers prune trees soon after in April. Pruning at this time can induce significant regrowth that could potentially compete with reproductive development and reduce yield and fruit quality.

In both experiments pruning immediately after harvest reduced yield. Pruning 1-2 months later did not reduce yield, but pruning when floral buds are present did reduce yields. This again demonstrates the importance of time of pruning.

Research in South Africa suggests that trees that have borne a crop should be pruned as soon as possible after harvest and trees pruned too late in the winter do not have sufficient time for bearer shoots to harden off and many flower buds that have initiated will be pruned away (Stassen, 1999). However, results here suggest that this may not be the case for Shepard. Pruning immediately after harvest in Shepard would result in excessive shoot growth by flowering time because of the earlier fruit harvest. Therefore a delay of several months is recommended, without much risk of reducing bearing wood.

There was no significant effect of pruning time on fruit quality. However, the results in southeast Queensland (section 1.3) indicate a risk to fruit quality if pruning allows excessive shoot growth at flowering. This again confirms the benefits of pruning several months after harvest of Shepard in north Queensland.

4 Effects of pruning and calcium application on yield and fruit quality in 'Hass' avocado

4.1 Introduction

Previous work on mechanical pruning on 'Hass' avocado in subtropical southeast Queensland indicates that pruning can reduce fruit quality, possibly by influencing the competition for nutrients within the tree. Experiments were established to investigate the effect of pruning on fruit mineral concentrations and postharvest quality. Calcium management in pruned trees was studied in relation to optimising fruit Ca concentrations because of its known effect on quality of avocado (Hofman *et al*., 2002) and other fruits (Hofman and Smith 1994). These experiments investigated both the use of soil applied gypsum and dolomite, and foliar chelated calcium (Calcimax® and Ligno-Calcium + Boron®).

4.2 Materials and Methods

4.2.1 Experimental sites and trees

Trees were pruned following the 2001 harvest and soil and foliar Ca applied at flowering and during early fruit set. Sunny® (1%) was also applied at flowering to reduce the spring flush. Non-pruned trees with and without Sunny® were also included.

4.2.2 Experiment 1 at Goodwood

Six-year-old trees were pruned at an angle of 20° after harvest on 2 August 2001. Gypsum and dolomite (4 kg/tree) and Sunny® (2.25 L/tree) and 0.5% Calcimax® (3 L/tree) were applied at flowering on 17 September. Calcimax® (3 L/tree) and Ligno-Calcium + Boron® (3 L/tree) were applied during early fruit set on 2 and 16 October (2 and 4 weeks after flowering), and 2, 16 and 30 October (2, 4 and 6 weeks after flowering), respectively. There were eight experimental treatments which were replicated six times in a randomised block design using single tree plots. Trees were harvested by 17 June 2002.

4.2.3 Experiment 2 at Childers

Seven-year-old trees were pruned at an angle of 15° after harvest on 25 August 2001. Gypsum (4 kg/tree) and Sunny® (2 L/tree) and 0.5% Calcimax® (2.25 L/tree) were applied at flowering on 17 September. Calcimax® (2.25 L/tree) and Ligno-Calcium + Boron® (2.25 L/tree) were applied during early fruit set on 2 and 16 October (2 and 4 weeks after flowering), and 2, 16 and 30 October (2, 4 and 6 weeks after flowering), respectively. There were eight experimental treatments which were replicated six times in a randomised block design using single tree plots. Trees were harvested on 31 July 2002.

4.2.4 Experiment 3 at Beerwah

Eight-year-old trees were left unpruned or pruned at an angle of 18° on 21 August 2001. Gypsum (5 kg/tree) was applied at flowering (20 October). There were four experimental treatments which were replicated seven times in a randomised block design using single tree plots. Trees were harvested on 26 June 2002.

4.2.5 Fruit size and yield

Fruit were harvested at maturity and the number and weight from each tree recorded.

4.2.6 Fruit quality and minerals

Twenty fruit was sampled at maturity from each tree at the three sites. Fruit were stored under simulated commercial conditions and assessed as previously described. Transverse equatorial sections of the flesh were sampled from 10 ripe fruit from each tree, oven-dried at 60°C and ground to a fine powder. Two sub-samples (0.5 g) were taken, one for nitrogen and the other for complete nutrient analysis. Nitrogen was determined after Kjeldahl digestion using sulphuric acid with selenium as a catalyst. After dilution the digest was read on an auto analyser method based on the indophenol reaction with salicylate and dichloroisocyanurate. The other elements were determined using an ICPOES spectrometer after digestion with nitric acid and hydrogen peroxide (University of Queensland laboratories).

4.2.7 Statistical analysis

Statistical analyses were by ANOVA and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means. Skewed data were angular transformed before analysis and back-transformed data is presented.

4.3 Results

4.3.1 Experiment 1 at Goodwood

4.3.1.1 Fruit size and yield

Pruning alone reduced yield compared with unpruned trees (Table 24). However, there was no negative effect of pruning when Sunny® was also applied. The other treatments except gypsum) were ineffective in increasing the yield to that of the non-pruned trees. Sunny® had no impact when it was applied to unpruned trees, but Sunny® again increased fruit weight when applied at flowering to pruned trees.

Table 24 Effects of pruning and calcium on yield, number of fruit and average fruit weight in 'Hass' avocado at Goodwood (Experiment 1) in 2001/02. Data are the means of six trees per treatment. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit /tree	Av. fruit wt. (g)
Unpruned	95.1a	19.0a	510a	187b
Unpruned + Sunny® at flowering	96.2a	19.2a	497a	197b
Pruned after harvest	45.2c	9.0c	233c	195b
Pruned after harvest + Sunny® at flowering	77.7ab	15.5ab	358bc	219a
Pruned + gypsum	79.0ab	15.8ab	417ab	190b
Pruned + dolomite	52.2c	10.4c	285bc	190b
Pruned + 0.5% Calcimax®	59.4bc	11.9bc	303bc	200b
Pruned + 1% Ligno-Ca+B®	55.3bc	11.1bc	295bc	192b

*t/ha was calculated from the tree spacing of 10 x 5 m (200 trees/ha).

4.3.1.2 Fruit quality and minerals

Pruning significantly ($P < 0.05$) affected ripening with fruit becoming soft in 7.7 days compared with 8.3 days in non-pruned trees (data not presented). Application of calcium increased the ripening time in pruned trees to 8.1-8.5 days. Pruning after harvest also increased the severity of stem-end rots and vascular browning (Table 25). None of the Ca applications applied to the pruned trees reduced fruit defects compared with pruning alone. However, both Calcimax and Ligno-Ca+B reduced stem end rots to levels similar to the non-pruned trees.

Pruning decreased fruit Ca concentrations compared with non-pruned trees (Table 26). Calcimax® increased fruit Ca in pruned trees, whereas the other treatments had no effect.

Table 25 Effects of pruning and calcium on the severity (% of flesh affected) of body and stem-end rots and vascular browning in 'Hass' avocado fruit stored under commercial conditions and ripened at 20ºC. Data are means of 120 fruit from six trees per treatment. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Severity (% of flesh affected)		
	Body rots	Stem-end rots	Vascular browning
Unpruned	0.16cd	0.11b	0.27cd
Unpruned + 1% Sunny® at flowering	0.06d	0.13b	0.18d
Pruned after harvest	0.37bcd	0.59a	0.78ab
Pruned + 1% Sunny® at flowering	0.35bcd	0.58a	0.72abc
Pruned + gypsum	1.02a	0.75a	1.18a
Pruned + dolomite	0.08d	0.78a	0.71bc
Pruned + 0.5% Calcimax	0.64abc	0.48ab	0.62bcd
Pruned + 1% Ligno-Ca+B	0.81ab	0.53ab	0.64bcd

Table 26 Effects of pruning and calcium application on fruit Ca concentration in 'Hass' avocado at Goodwood (Experiment 1) in 2002. Data are the means of six trees. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Fruit Ca concentration (%)
Unpruned	0.060a
Pruned after harvest	0.046c
Pruned after harvest + 1% Sunny® at flowering	0.052abc
Pruned + gypsum	0.049bc
Pruned + dolomite	0.054abc
Pruned + 0.5% Calcimax	0.056ab
Pruned + 1% Lig-Ca+B	0.050bc

4.3.2 Experiment 2 at Childers

4.3.2.1 Fruit size and yield

Trees pruned and supplied with calcium had lower yields compared with unpruned trees whereas there was no effect of pruning alone or Sunny® (Table 27). These effects were mainly through fruit number per tree. Both Sunny® treatments increased fruit weight compared with their respective controls.

Table 27 Effects of pruning and calcium on yield, number of fruit and average fruit weight in 'Hass' avocado at Childers (Experiment 2) in 2001/02. Data are the means of six trees per treatment. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt.(g)
Unpruned	44.8a	14.9a	236a	192d
Unpruned+Sunny® at flowering	45.6a	15.2a	211ab	219ab
Pruned after harvest	33.6ab	11.2ab	184abc	197cd
Pruned after harvest+Sunny® at flowering	42.0a	14.0a	188abc	227a
Pruned+gypsum	27.4b	9.1b	139bc	208abcd
Pruned+0.5% Calcimax®	25.6b	8.5b	128c	207bcd
Pruned+1% Calcimax®	27.5b	9.2b	136bc	206bcd
Pruned+1% Ligno-Ca+B®	25.8b	8.6b	121c	216abc

*t/ha was calculated from the tree spacing of 5 x 6 m (333 trees/ha).

4.3.2.2 Fruit quality and mineral analysis

There was no effect of pruning or Ca application on fruit rots, disorders or mineral concentrations.

4.3.3 Experiment 3 at Beerwah

4.3.3.1 Fruit size and yield

Pruning reduced yield compared with unpruned trees and increased average fruit weight (Table 28). Gypsum had no effect.

Table 28 Effects of pruning and calcium on yield, number of fruit and average fruit weight in 'Hass' avocado at Beerwah (Experiment 3) in 2001/02. Data are the means of seven trees per treatment. Means followed by the same letters are not significantly different (*P* > 0.05).

Treatment	Yield (kg/tree)	Yield (t/ha*)	No. of fruit/tree	Av. fruit wt. (g)
Unpruned	54.2a	10.9a	251a	225b
Unpruned + gypsum	66.3a	13.3a	318a	215b
Pruned after harvest	22.3b	4.5b	81b	282a
Pruned + gypsum	20.4b	4.1b	73b	286a

*t/ha was calculated from the tree spacing of 10 x 5 m (200 trees/ha).

4.3.3.2 Fruit quality and minerals

Pruning significantly affected ripening, with fruit becoming soft 2.8 days after removal from storage, compared with 4.7 days in unpruned trees (data not presented). Calcium increased the ripening time to 3.1 days in pruned trees and 5.0 days in unpruned trees. There was no effect of pruning or Ca on the severity or incidence of fruit rots and disorders.

Pruning reduced Ca and increased N concentrations in the fruit (Table 29). Pruning also increased the N/Ca ratio, while pruning+gypsum reduced the (Ca+Mg)/K ratio in the fruit compared with no treatment.

Table 29 Effects of pruning and calcium on fruit mineral concentration in 'Hass' avocado at Beerwah (Experiment 3) in 2002. Calcium (Ca), nitrogen (N) as % of dry mass and the N/Ca and (Ca + Mg)/K ratios are presented. Data are the means of seven trees. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Flesh concentration (%)		N/Ca	(Ca + Mg)/K
	Ca %	N %		
Unpruned	0.032a	0.88b	27.9a	0.067ab
Unpruned + gypsum	0.037a	0.85b	24.3a	0.074a
Pruned after harvest	0.025b	1.11a	46.7b	0.060bc
Pruned + gypsum	0.025b	1.03a	40.9b	0.058c

4.4 Discussion

The above results indicate that pruning after harvest reduces yield, hastens ripening, increases fruit rots and disorders, and reduces fruit Ca concentrations. The trees were pruned for the first time and considerable vegetative growth (2-2.5 m) was removed. Previous trials have shown that after 2-3 years, there was no difference in yield between pruned and unpruned trees.

Mineral nutrition of avocado has a significant effect on postharvest quality (Whiley and Hofman, 2000). Calcium is the most frequently implicated mineral and there are numerous reports on its effect on fruit quality (Hofman and Smith, 1994). Low fruit Ca concentrations have been associated with several undesirable fruit characteristics, including rapid softening after harvest (Wills and Tirmazi, 1982), susceptibility to chilling injury (Chaplin and Scott, 1980) and flesh disorders (Bower and Cutting, 1988; Cutting *et al*., 1992; Thorp *et al*., 1997). The incidence of anthracnose following postharvest handling has also been reported to increase with low concentrations of fruit Ca (Vuthapanich, 2001).

Fruit Ca concentrations are influenced by several factors, including soil Ca, tree vigour, rootstocks, N nutrition and crop load. Competition between vegetative and reproductive growth, especially in the 6-10 weeks after fruit set has been reported to effect fruit Ca concentrations (Witney *et al*., 1990). The timing of pruning is critical and can result in regrowth during fruit set.

Several strategies have been investigated to improve fruit Ca concentrations. Calcium application can increase fruit Ca in pruned trees, however excessive soil Ca concentrations may reduce the uptake of nutrients such as K and Mg. The results here also demonstrated that excessive vegetative growth, as stimulated by pruning, can reduce fruit Ca concentration.

Foliar sprays of Ca during fruit growth have been reported to have little effect on flesh concentrations due to poor absorption by the fruit, and poor translocation within the tree. Veldman (1983) reported that foliar calcium nitrate had little effect on fruit Ca in avocado and did not reduce pulpspot, a flesh disorder common in fruit with low Ca concentrations. However, Penter and Stassen (1999) reported that 0.5% or 1.0% chelated calcium (Calcimax®) sprayed three weeks after fruit set reduced the incidence of grey pulp and vascular browning in 'Edranol' avocado. The current results suggest that Calcimax® can increase fruit Ca concentration and potentially quality in some instances, but the responses are not consistent.

Application of Sunny® at mid-bloom has been reported to suppress spring growth flush and improve fruit quality (Whiley, 2001) possibly as a result of increased fruit Ca concentrations due to the reduction in vegetative:reproductive competition. However, in this trial there was no effect of Sunny® on fruit Ca or quality.

Further work on mineral nutrition in pruned avocado orchards is required before recommendations on fertiliser rates can be made.

5 Effects of prohexadione-calcium on yield and fruit quality and naphthalene acetic acid on shoot growth in ‘Hass’ avocado

5.1 Introduction

Plant growth regulators have been successfully used to manipulate vegetative growth, and increase flowering, yield and fruit size in avocado. Triazoles, a group of plant growth retardants that inhibit gibberellin biosynthesis (Davis *et al*., 1988) are particularly effective (Köhne and Kremer- Köhne, 1987; Köhne, 1988; Adato, 1990; Wolstenholme *et al*., 1990; Whiley *et al*., 1991; Penter *et al*., 2000; Whiley, 2001).

Other growth regulators are also available that can control vegetative growth. Prohexadione-calcium (a GA biosynthesis inhibitor) known as Apogee® when applied at 0.25 g/l in avocado at the cauliflower stage of inflorescence development, at anthesis and during fruit set as a single treatment significantly delayed the elongation of the vegetative shoot of indeterminate floral shoots and increased fruit set measured in August in the USA (Lovatt, 2001). However, there was no significant effect on yield. In Chile, Apogee® at 1.25g/l at full bloom increased yields of avocado from 14.8 to 22.1 t/ha (A.W. Whiley, personal communication). Auxins such as naphthalene acetic acid (NAA) have also been shown to control regrowth on avocado stumps following top-working (Boswell *et al*., 1976) and to minimise regrowth following pruning in ‘Reed’ avocado in California (A.W. Whiley, personal communication).

Trials were conducted on ‘Hass’ avocado to determine the effects of prohexadione-calcium on yield and fruit quality, and to evaluate the effects of NAA on growth following heavy pruning.

5.2 Materials and Methods

5.2.1 Prohexadione-calcium (Apogee®)

The experiment was conducted in a commercial orchard at Childers (latitude 25ºS) on 4-year-old ‘Hass’ avocado trees. Prohexadione-calcium as Apogee® (BAS 125 10 W) at 0.5, 0.75, 1.0 and 1.25 g/l was applied at mid-bloom on 2 September 2003 using a motorised, backpack spray unit (Stihl, Germany). Trees were sprayed to the point of run-off using 1.25 l per tree, with Agral® at 0.05%. Non-sprayed and a water+Agral® treatment were included. Treatments were replicated seven times in a randomised block design using single tree plots. Statistical analyses were by ANOVA and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means. The treatments were:

1. Unsprayed
2. Water spray
3. Apogee® (0.5 g/l)
4. Apogee® (0.75 g/l)
5. Apogee® (1.0 g/l)
6. Apogee® (1.25 g/l)

Trees were harvested on 18 May 2004 and the number and weight of fruit recorded from each tree. Fruit quality of 20 fruit per tree from treatments 1, 3, 4 and 5 was assessed as previously described.

5.2.2 NAA

Two experiments were carried out to study the effects of NAA on growth of 'Hass' trees in a commercial orchard at Halfway Creek, south of Grafton in northern NSW (latitude 30ºS).

In the first experiment, the upper branches of five-year-old trees were pruned on 11 December 2003. Branches 2-3 cm in diameter were painted with acrylic paint or with a 0.5 or 1% NAA + paint formulation. The paint was applied to the cut surface and 20 cm down the branch. Treatments were applied to 10 branches from two trees.

In the second experiment 14-year-old trees were pruned 'hard' on the eastern side of the tree on 4 November 2003. On 11 December, branches 8-15 cm in diameter were painted with acrylic paint or with a 0.5 or 1% NAA + paint formulation. Treatments were applied to 12 branches from four trees.

The number and length of regrowth shoots within and below the painted section of the branch were measured on 23 April 2004. Statistical analyses were by ANOVA and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means.

5.3 Results

5.3.1 Apogee®

Apogee® had no significant ($P > 0.05$) effect on yield or average fruit weight (data not shown). In contrast, the product at 1.25 g/l reduced the severity and incidence of body rots compared with unsprayed trees (Figs. 5 and 6). In addition, the product at all concentrations reduced the severity and incidence of stem-end rots and vascular browning.

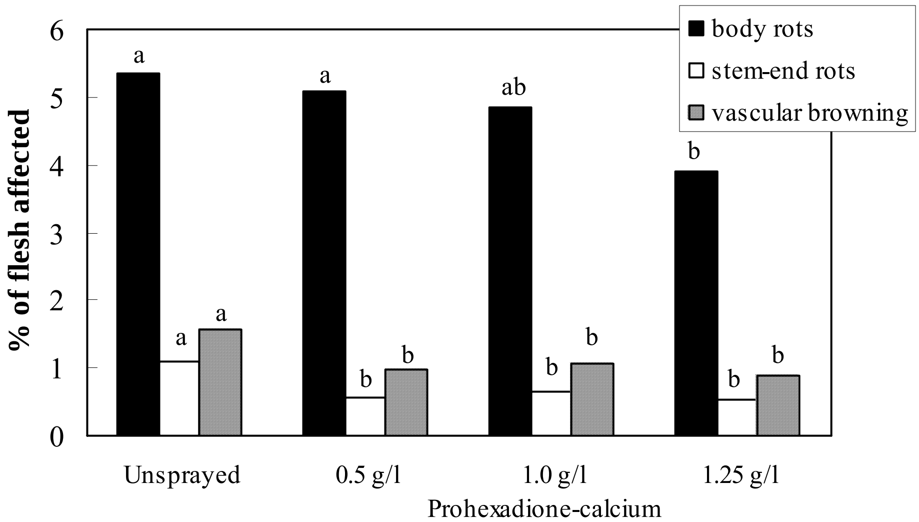

Fig. 5 Effects of Apogee® on the severity of body rots, stem-end rots and vascular browning in 'Hass' avocado fruit stored under simulated commercial conditions and ripened at 20ºC. Means with different letters are significantly different ($P < 0.05$).

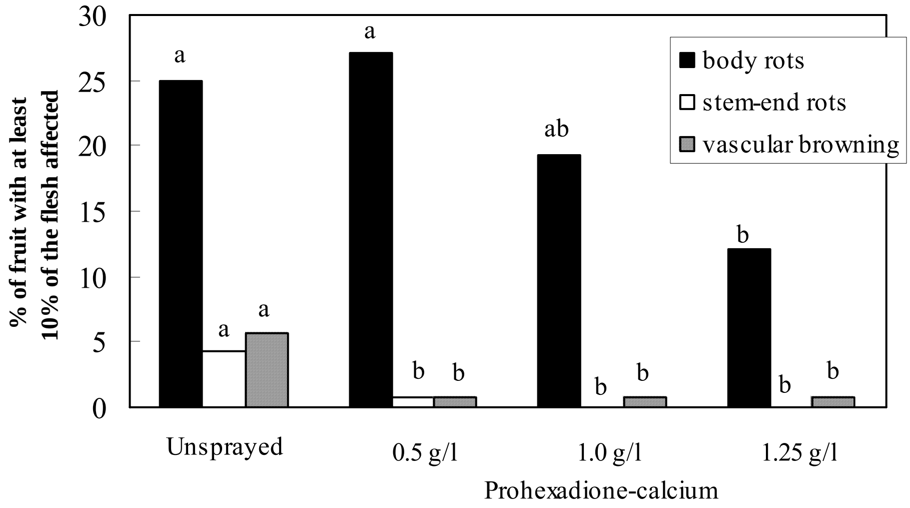

Fig. 6 Effects of Apogee® on the incidence of body rots, stem-end rots and vascular browning in 'Hass' avocado fruit stored under simulated commercial conditions and ripened at 20ºC. Means with different letters are significantly different ($P < 0.05$).

5.3.2 NAA

NAA reduced regrowth in the painted section of the branch, although growth occurred below the treated area (Table 30).

Table 30 Effects of NAA treatment on regrowth in pruned branches in 'Hass' avocado trees. Data are means of 10 branches from two, 5-year-old trees and 12 branches from three, 14-year-old trees. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	No. of shoots in treated area	Length of shoot (cm)	No. of shoots below treated area	Length of shoot (cm)
5-year-old				
Paint only	3.8a	89.6a	0	0
0.5% NAA	0.1b	4.0b	2.3a	43.9a
1% NAA	0	0	2.2a	41.8a
14-year-old				
Paint only	4.9a	65.1a	0	0
0.5% NAA	0.9b	19.4b	3.9a	64.4a
1% NAA	0.2b	7.5b	2.3a	58.9a

5.4 Discussion

Lovatt (2001) noted that Apogee® at 0.25 g/l increased early fruit retention, but did not increase final yield. Similar nil effects on yield were noted in the present trials. However these results were contradictory to those in Chile, where Apogee® at 1.25 g/l applied at full bloom significantly increased yield from 14.8 to 22.1 t/ha (A. W. Whiley, personal communication). The reasons for these differences are not clear.

Lovatt (2001) also noted that Apogee® delayed the elongation of the vegetative growth of indeterminate floral shoots. This may have contributed to the increased fruit retention, and also to the improved fruit quality in the present trial.

NAA has been successfully used to control regrowth on avocado stumps following top-working (Boswell et al., 1976) and has been reported to effectively control regrowth for up to 18 months following pruning of the central leader in 'Reed' avocado in California (A.W. Whiley, personal communication). Similar effects were noted here, but shoot growth below the treated area may require larger areas of the trunk to be painted, or a higher concentration of NAA used in the paint

Further trials are being conducted to investigate the effectiveness of these chemicals under Australian growing conditions.

6 Effect of mulching on yield, fruit size and quality and root growth in 'Hass' avocado

6.1 Introduction

'Hass' is the mainstay of the Australian avocado industry, but can produce small fruit with low market acceptance. In South Africa, 5-25% of the fruit produced is regarded as too small and in warm, dry growing conditions this can increase to 40% in older and stressed trees (Kremer-Köhne and Köhne, 1995). Whiley and Schaffer (1994) noted that 'Hass' fruit are 30% smaller in warm subtropical coastal southeast Queensland compared with those from a cool highland environment.

Although fruit size is ultimately genetically determined, several management strategies including plant growth regulators (Adato 1990; Whiley *et al*., 1991; Erasmus and Brooks, 1998; Penter *et al*., 2000; Whiley, 2001) selective harvesting (Kaiser and Wolstenholme, 1994; Whiley *et al*., 1996) and mulching (Moore-Gordon *et al*., 1996; 1997; Wolstenholme *et al*., 1998) can alleviate the small fruit problem.

This study investigated the effect of mulches on yield, fruit size, fruit quality and root growth in 'Hass' avocado grown in warm subtropical Childers and Bundaberg in southeast Queensland.

6.2 Materials and Methods

6.2.1 Experiment 1 at Childers

Four-year-old 'Hass' trees, growing in a deep, well-drained krasnozem soil (ca. 65% clay) were mulched on 25 August 1999 using sorghum hay, sugarcane tops, pine woodchip and pine-bark, with an unmulched control included. The mulches were applied under the canopy to a depth of 10 cm, with only a single application. Experimental treatments were replicated eight times in a completely randomised design using single tree plots.

Fruit was harvested on 3 July 2000, 2 August 2001 and 31 July 2002 and the number and weight of fruit from each tree recorded.

In 2001, 20 fruit were sampled at maturity from each tree and stored under simulated commercial conditions as described before. The severity (% of flesh affected) and incidence (% of fruit affected) of fruit rots and disorders were recorded.

6.2.2 Experiment 2 at Bundaberg

Four-year-old 'Hass' trees growing on sandy loam soil were mulched in September 2001 using sugarcane tops, filter-press (a by-product of sugarcane processing) and pine woodchip with an unmulched control included. A second application of sugarcane tops and filter press were made in September 2002.

Treatments were arranged into six blocks of four trees. At each harvest fruit from the middle two trees in each block were pooled and fruit placed through a commercial packing shed. The number of fruit in each size category was determined for each treatment.

In 2003, 20 fruit were sampled at maturity from each of 12 trees from the four mulch treatments, stored and quality assessed as before.

On 21 January 2002, 'root windows' were created by scraping back the mulch and about 1 cm of soil and placing a clear perspex sheet (500 x 500 x 2 mm) on the soil at two sites under the tree canopy 30 cm from the trunk. The perspex sheets were covered with black foam (5 mm) to prevent light penetration and the soil and mulch replaced. The length of the visible non-suberised roots (usually white to light brown) were measured on 12 March and 5 October by removing the mulch and black foam, and tracing the outline of roots visible at the soil-perspex interface onto transparent sheets of acetate with a black permanent marker. The root tracings were scanned to an electronic file using a digital scanner (HP Scanjet; Hewlett Packard, USA) and the total root length determined by computerised image analysis (Delta-T Scan® version 2.0, Delta-T Devices Ltd., UK). The total length (m) of non-suberised roots for each perspex sheet was calculated (0.25 m^2 area).

6.2.3 Statistical analysis
Statistical analyses were by ANOVA and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means. Skewed data were angular transformed before analysis and back-transformed data is presented.

6.3 Results

6.3.1 Experiment 1

6.3.1.1 Fruit size and yield
There was no significant ($P > 0.05$) effect of mulching on yield or fruit size over the three years (data not presented).

6.3.1.2 Fruit quality
The addition of woodchip and pine-bark reduced the severity of diffuse discolouration of the flesh with 0.9 and 1.2% of the fruit affected compared with 2.1% in the unmulched control trees (data not presented).

6.3.2 Experiment 2

6.3.2.1 Fruit size, yield and quality
There was no significant ($P > 0.05$) effect of mulching on yield, average fruit size or counts per tray over the two years, and no effect of mulching on fruit quality in the second year (data not presented).

6.3.2.1 Root growth
There was no effect of mulching on root growth measured on 12 March 2002 (Table 31). However, on 5 October the mean length of non-suberised roots was greater after mulching with sugarcane tops and woodchip compared with unmulched trees.

Table 31 Effect of mulching on the root growth in 'Hass' avocado trees at Bundaberg (Experiment 2) in 2002. Data are the means of six trees. Means followed by the same letters are not significantly different ($P > 0.05$).

Treatment	Total, non-suberised root length (m)	
	12th March	5th October
No Mulch	2.6a	3.4c
Woodchip	4.9a	8.0a
Filter-press	3.4a	4.9bc
Sugarcane tops	5.4a	6.6ab

6.4 Discussion

In warm subtropical southeast Queensland mulching did not increase fruit size and yield in 'Hass' avocado. However, mulching improved fruit quality at one site with a reduction in the severity of diffuse discolouration of the flesh in fruit sampled from trees mulched with woodchip and pine-bark. In addition, root growth was enhanced in trees mulched with woodchip and sugarcane tops.

The benefit of maintaining high levels of organic matter to suppress *Phytophthora cinnamoni* (root rot) activity is well documented, and mulching trees to maintain tree health is widely practiced in some countries (Broadbent and Baker, 1974; Pegg and Whiley, 1987). Application of composted pine-bark increased fruit size by 6.6%, increased mean fruit numbers per tree by 14.7% and increased yield by 22.6% (Moore-Gordon *et al*., 1996; 1997 and Wolstenholme *et al*., 1998). These improvements in tree performance are likely due to improved root growth that was observed under mulched trees, resulting in a reduction in pedicel ring-neck and premature seed coat degeneration (Wolstenholme *et al*., 1998). However, in the current study increased root activity did not result in an improvement in fruit size and yield.

Mulching has also been reported to increase water and nutrient availability to the tree (Gregoriou and Rajkumar, 1984). However, the choice of mulching material will alter the irrigation and nutritional requirements of the tree. The carbon:nitrogen (C:N) ratio of the mulch according to Wolstenholme *et al*.(1998) should be between 25:1 and 100:1 to avoid serious nitrogen draw-down that can occur when sawdust is used (C:N ratio of 400-500). However, some N drawdown may be good under conditions of excess N. This may have been one of the causes for the reduced diffuse discolouration with pine bark and wood chip in one trial, since these have a relatively high C:N ratio, and lower fruit is often associated with reduced fruit disorders (Hofman and Smith 1994).

The impact of mulching on water and nutritional requirements were not investigated in the current study and need to be addressed before grower recommendations can be made.

Recommendations

Pruning can be used to control tree size, but the timing of pruning will determine the success of this canopy management strategy. Pruning soon after harvest may induce vegetative growth that can compete with the developing fruit and reduce fruit quality. In subtropical southeast Queensland trees harvested by June should be pruned between 1-2 months after harvest to minimise regrowth and maintain fruit quality.

The success of summer pruning is dependent on establishing and maintaining a tree shape at fruit set so that further pruning can be implemented in the presence of the crop. The timing of summer pruning is also critical with respect to producing new shoots that are sufficiently mature to flower the following spring. Trees should be pruned no later than December to avoid reduced flowering in shoots the following spring.

Foliar application of Sunny® at flowering increased fruit size by 7-16% and can be of commercial benefit in locations where small fruit size is a problem. Sunny® applied to the regrowth following summer pruning will reduce length and increase flowering the following spring.

Low fruit Ca has been associated with poor fruit quality. Pruning immediately after harvest can reduce the Ca concentration in the fruit. This further justifies pruning 1-2 months after harvest. Several Ca formulations were tested to increase fruit Ca in pruned trees. Foliar Ca (Calcimax®) increased the Ca concentration in the fruit in pruned trees at only one site, and the other Ca formulations had not effect. Further work on calcium nutrition in pruned orchards is required before recommendations can be made.

Preliminary data suggests that Apogee (prohexadione-calcium) and naphthalene acetic acid (NAA) may be useful canopy management tools. Preliminary trials showed that mid-bloom foliar applications of Apogee at 1.25 g/l reduced in the incidence of body rots. Application of NAA to branches following pruning reduced regrowth in the treated area however regrowth was encouraged further down the branch. Further trials on the effect of prohexadione-calcium and NAA are being conducted before these products can be registered for use in avocado.

In these trials mulching was shown to enhance root activity and improve fruit quality for some mulching treatments. The impact of mulching on water and nutritional requirements were not investigated, but needs to be addressed before grower recommendations can be made.

This research was conducted on ‘Hass’ avocado in southeast Queensland (Childers/Bundaberg) and ‘Shepard’ avocado in north Queensland (Mareeba). Further work is required in other production areas before industry-wide recommendations can be made.

Technology Transfer

Field days

August-September 2002 – results to date were presented to growers at Bundaberg, Hampton, Beerwah, Alstonville and Grafton.

July-November 2003 – Developments in canopy management were presented to growers at Atherton, Bundaberg, Gatton, Duranbah, Stuart's Point, Renmark and Pemberton as part of the Australian Avocado Growers Federation's R&D Road Show.

Conference and 'Talking Avocados' papers

Leonardi, J. (2001) Progress in canopy management of avocados. In: *Proceedings of the Australian and New Zealand Avocado Growers' Conference 'Vision 2020'*. Conference CD, Australian Avocado Growers' Federation, Brisbane, Session 7/18, 11pp.

Leonardi, J. (2001) Progress in canopy management of avocados. *Talking Avocados* 12(4), 14-17.

Leonardi, J. (2003) Update on canopy management of avocados. *Talking Avocados* 14(1), 8-12.

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References

Adato, I. (1990) Effects of paclobutrazol on avocado (*Persea americana* Mill.) cv. 'Fuerte'. *Scientia Horticulturae* 45, 105-115.

Biran, D. (1979) Fruitlet abscission and spring growth retardation – their influence on avocado productivity. MSc thesis, The Hebrew University of Jerusalem, Israel (in Hebrew).

Blumenfeld, A., Gazit, S. and Argaman, E. (1983) Factors involved in avocado productivity. Special Publ. No. 222, Department of Subtropical Horticulture, Volcani Centre, Bet-Dagan, Israel. Pp 84-85.

Boswell, S.B., Bergh, B.O. and Whitsell, R.H. (1976) Control of sprouts on topworked avocado stumps with NAA [naphthaleneacetic acid] formulations. *HortScience* 11, 113-114.

Bower, J.P. and Cutting, J.G.M. (1988) Avocado fruit development and ripening physiology. *Horticultural Reviews* 10, 229-271.

Broadbent, P. and Baker, K.E. (1974) Behaviour of *Phytophthora cinnamomi* in soils suppressive and conducive to root rot. *Australian Journal of Agricultural Research* 25, 121-137.

Cain, J.C. (1972) Hedge row orchard design for most efficient interception of solar radiation. Effects of tree size, shape, spacing and row direction. *Search Agriculture* 2(7), 1-15.

Chaplin, G.R. and Scott, K.J. (1980) Association of calcium in chilling injury susceptibility of stored avocados. *HortScience* 15, 514-515.

Coates, L., Cooke, T, Persley, D., Beattie, B. and Wade, N. (eds.). (1995) Postharvest Diseases of Horticultural Produce. Volume 2: Tropical Fruit. Department of Primary Industries, Queensland, Brisbane.

Cutting, J.G.M. and Bower, J.P. (1990) Spring vegetative flush removal: The effect on yield, size, fruit mineral composition and quality. *South African Avocado Growers' Association Yearbook* 13, 33-34.

Cutting, J.G.M., Wolstenholme, B.N. and Hardy, J. (1992) Increasing the relative maturity alters the base mineral composition and phenolic concentration of avocado fruit. *Journal of Horticultural Science* 67, 761-768.

Davis, T.D., Steffens, G.L. and Sankhla, N. (1988) Triazole plant growth regulators. *Horticultural Reviews* 10, 63-105.

Erasmus, H.D. and Brooks, W.H. (1998) Foliar application of uniconazole (Sunny®) to avocado trees to improve fruit size and yield and to change fruit shape. South African Avocado Growers' Association Yearbook 21, 52-53.

Gregoriou, C. and Rajkumar, D. (1984) Effect of irrigation and mulching on shoot and root growth of avocado (*Persea americana* Mill.) and mango (*Mangifera indica* L.). *Journal of Horticultural Science* 59, 109-117.

Hofman, P.J., Smith, L.G. (1994) Preharvest effects on postharvest quality of subtropical and tropical fruit. In: Champ, B.R., Highley, E., Johnson, G.I. (Eds.), Postharvest handling of tropical fruits. Australian Centre for International Agricultural Research, Canberra, pp. 261-268.

Hofman, P.J., Vuthapanich, S., Whiley, A.W., Klieber, A. and Simons, D. (2002) Tree yield and fruit minerals concentrations influence 'Hass' avocado fruit quality. *Scientia Horticulturae* 92, 113-123.

Kaiser, C. and Wolstenholme, B.N. (1994) Aspects of delayed harvest of 'Hass' avocado (*Persea americana* Mill.) fruit in a cool subtropical climate. II. Fruit size, yield, phenology and whole-tree starch cycling. *Journal of Horticultural Science* 69, 447-457.

Köhne, J.S. (1988) Response of avocado (*Persea americana* Mill.) to the growth regulator paclobutrazol. *Applied Plant Science* 2, 40-43.

Köhne, J.S. and Kremer- Köhne, S. (1987) Vegetative growth and fruit retention in avocado as affected by a new plant growth regulator (paclobutrazol). *South African Avocado Growers' Association Yearbook* 10, 64-66.

Kremer-Köhne, S. and Köhne, J.S. (1995) Approaches to solving the small Hass fruit problem: progress report. *South African Avocado Growers' Association Yearbook* 18, 59-60.

Lovatt, C.L. (2001) Developments in plant growth regulators: Manipulation of vegetative growth, flowering and fruiting of avocados. In: *Proceedings of the Australian and New Zealand Avocado Growers' Conference 'Vision 2020'*. Conference CD, Australian Avocado Growers' Federation, Brisbane, 7pp.

Moore-Gordon, C., Cowan, A.K. and Wolstenholme, B.N. (1997) Mulching of avocado orchards to increase Hass yield and fruit size and boost financial rewards – a three season summary of research findings. *South African Avocado Growers' Association Yearbook* 20, 46-49.

Moore-Gordon, C., Wolstenholme, B.N. and Levin, J. (1996) Effect of composted pinebark mulching on *Persea americana* Mill. Cv. Hass fruit growth and yield in a cool subtropical environment. *Journal of South African Horticultural Science* 6, 23-26.

Pegg, K.G. and Whiley, A.W. (1987) Phytophthora control in Australia. *South African Avocado Growers' Association Yearbook* 10, 94-96.

Penter, M.G. and Snijder, B. (2001) Avocado tree management – a holistic approach: Chemical manipulation. *South African Avocado Growers' Association Yearbook* 24, 52-54.

Penter, M.G. and Stassen P.J.C. (1999) Chemical manipulation as part of management programme for improved fruit yield and quality in avocado orchards. *South African Avocado Growers' Association Yearbook* 22, 69-75.

Penter, M.G., Snijder, B., Stassen P.J.C. and Schäfer, E. (2000) The effect of growth inhibitors on fruit production in Hass avocado trees. *South African Avocado Growers' Association Yearbook* 23, 46-51.

Scholefield, P.B., Sedgley, M. and Alexander, D.McE. (1985) Carbohydrate cycling in relation to shoot growth, floral initiation and development and yield in avocado. *Scientia Horticulturae* 25, 99-110.

Stadler, J.D. and Stassen, P.J.C. (1985) Pruning and training deciduous fruit trees: 1. Lighting, density and pruning procedures. *FFTRI Information Bulletin* No. 531.

Stassen, P.J.C. (1999) Pruning of avocado orchards: Strategies for rehabilitating avocado jungles. Neltropika Bulletin 306:16-22.

Stassen, P.J.C. and Davie, S.J. (1996) Manipulation of avocado trees – Pruning. *South African Avocado Growers' Association Yearbook* 19, 73-76.

Stassen, P.J.C., Snijder, B. and Bard, Z.J. (1999*a*) Results obtained by pruning overcrowded avocado orchards. *Revista Chapingo Serie Horticultura* 5, 165-171.

Stassen, P.J.C., Snijder, B. and Donkin, D.J. (1999*b*) Results with spacing, tree training and orchard maintenance in young avocado orchards. *Revista Chapingo Serie Horticultura* 5, 159-164.

Thorp, T.G., Hutching, D., Lowe, T. and Marsh, K.B. (1997) Survey of fruit mineral concentrations and postharvest quality of New Zealand-grown 'Hass' avocado (*Persea americana* Mill.). *New Zealand Journal of Crop and Horticultural Science* 25, 251-260.

Veldman, G. (1983) Kalsiumnitraat bespuitings op avokados te Westfalia-landgoed met die doel om puplvlek te verminder. *South African Avocado Growers' Association Yearbook* 26, 64-65.

Vuthapanich, S. (2001) Preharvest practices affecting postharvest quality and mineral composition of 'Hass' avocado fruit. Unpublished PhD thesis. University of Queensland, Australia.

Whiley, A.W. (2001) Adoption of field practices to assist in expanding avocado markets. In: *Proceedings of the Australian and New Zealand Avocado Growers' Conference 'Vision 2020'*. Conference CD, Australian Avocado Growers' Federation, Brisbane, Session 1/1, 22pp.

Whiley, A.W. and Hofman, P.J. (2000) Mineral nutrition of avocados: a review. Queensland Horticulture Institute, 45pp.

Whiley, A.W., Rasmussen, T.S., Saranah, J.B. and Wolstenholme, B.N. (1996) Delayed harvest effects on yield, fruit size and starch cycling in avocado (*Persea americana* Mill.) in two subtropical environments. II. The late-maturing cv. Hass. *Scientia Horticulturae* 66, 35-49.

Whiley, A.W., Saranah, J.B., Wolstenholme, B.N. and Rassmussen, T.S. (1991) Use of paclobutrazol sprays at mid-anthesis for increasing fruit size and yield of avocado (*Persea americana* Mill. cv Hass). *Journal of Horticultural Science* 66, 593-600.

Whiley, A.W. and Schaffer, B. (1994) Avocado. In: *CRC Handbook of Environmental Physiology of Fruit Crops* Vol. II. (Eds) B. Schaffer and P.C. Anderson, CRC Press Inc., Boca Raton, Florida, pp. 3-35.

White, A., Woolf, A.B. and Hofman, P.J. (2001) Avocare Assessment Manual. HortResearch, Auckland, New Zealand.

Wills, R.B.H. and Tirmazi, S.I.H. (1982) Inhibition of ripening of avocados with calcium. *Scientia Horticulturae* 16, 323-330.

Witney, G.W., Hofman, P.J., and Wolstenholme, B.N. (1990) Effect of cultivar, tree vigour and fruit position on calcium accumulation in avocado fruits. *Scientia Horticulturae* 44, 269-278.

Wolstenholme, B.N., Whiley, A.W. and Saranah, J.B. (1990) Manipulating vegetative:reproductive growth in avocado (*Persea americana* Mill.) with paclobutrazol sprays. *Scientia Horticulturae* 41, 315-327.

Wolstenholme, B.N., Moore-Gordon, C.S. and Cowan, A.K. (1998) Mulching of avocado orchards: Quo Vadis? *South African Avocado Growers' Association Yearbook* 21, 26-28.