Evaluation of sustainable orchard management practices for extension into general industry standards to reduce costs

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Project Number: AV08020

AV08020

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the avocado industry.

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

ISBN 0 7341 3086 4

Published and distributed by:
Horticulture Australia Ltd
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179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
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HAL
Horticulture Australia

AV08020 (December 2012)

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Project Purpose: The objective of this project was to identify sustainable orchard management practices used by avocado growers across Australia; conduct trials to evaluate the effectiveness of some of these strategies, and provide recommendations to the wider industry on the most promising practices.

Date: December 2012

This project has been funded by HAL using the avocado levy and matched funds from the Australian Government.

Contents

Media Summary

There are increasing demands on avocado growers to optimise fruit yield and quality, reduce chemical use, develop market opportunities and meet consumer expectations to remain competitive. An increase in public awareness and concern for the environment has also led to an increase in demand for 'safer' food and more environmentally sensitive production methods.

The objective of this project was to identify sustainable orchard management practices that could be used by avocado growers across Australia; to conduct trials to evaluate the effectiveness of some of these strategies; and provide recommendations to the wider industry on the most promising practices.

Several orchard management practices and products are being used by avocado growers including: mulching, natural mineral fertilisers, fish and kelp concentrates, composts teas and other brewed microbes, molasses and branch scoring.

The effect of different mulches on tree growth, yield and fruit quality was investigated in Central Queensland over three consecutive years. Trees were mulched with filter-press (a sugar industry by-product), cane-tops and avocado woodchip at flowering during September each year. Mulching trees with avocado woodchip and to a lesser extent cane-tops increased cumulative yield compared with trees receiving minimal mulch. The increase in yield may be due to the tendency for increased root growth observed in these mulched trees.

Trials investigating the effect of a range of soil and foliar treatments were also conducted. Foliar application of pyroligneous acid (PandA®) an organic liquid derived from heating bamboo to 250-350°C in combination with a copper fungicide treatment can increase fruit quality with a reduction in the incidence of fruit rots and disorders. Soil and foliar applications of microbial products (TwinN® & BB5®) can increase root growth in avocado. This increase in root growth and possible nutrient uptake may be responsible for improvements in shoot growth, tree health and fruit quality observed at some of the experimental sites.

The effect of branch scoring on fruit size and yield was investigated at several sites across Australia. Scoring involves cutting a groove no more than 3mm wide around the branch to sever the phloem using a knife or pruning saw. Results indicate that branch scoring may provide a non-chemical approach for increasing cropping in vigorous avocado trees, particularly in southern growing regions. However this technique is still experimental and may not necessarily work under all growing conditions.

Although results of this work demonstrate some improvements in tree growth, yield and fruit quality further discriminatory testing on these sustainable management practices is necessary before grower recommendations can be made.

Technical Summary

Many avocado growers have adopted sustainable orchard management practices to optimise fruit yield and quality, reduce chemical use, develop market opportunities and address the increase in consumer sentiment for 'safer' food and more environmentally sensitive production methods.

The objective of this project was to identify sustainable orchard management practices used by avocado growers across Australia; conduct trials to evaluate the effectiveness of some of these strategies; and provide recommendations to the wider industry on the most promising practices.

Several orchard management practices and products are being used by avocado growers including: mulching, natural mineral fertilisers, fish and kelp concentrates, composts teas and other brewed microbes, molasses and branch scoring.

The effect of the mulching over three consecutive years on tree growth, yield and fruit quality in 'Hass' avocado grown in subtropical Central Queensland. Trees were mulched with filter-press (a sugar industry by-product), cane-tops and avocado woodchip. A grower treatment (inter-row slashings with a thin layer of filter-press) was included for comparison. Additional mulching trials over one cropping season were also established on 'Shepard' and 'Hass' trees in tropical North Queensland. A composted product (derived from vegetation waste), Rhodes grass hay, and a combination of the two products were applied to 2½ year old 'Shepard' and 'Hass' trees. A grower treatment (inter-row slashings) was included for comparison.

Pyroligneous acid has been reported to improve root, shoot and fruit growth, increase resistance to pests and diseases, reduce leaf fall and fruit drop, and improve yield and fruit quality in several crops. The effect of soil and foliar applications of pyroligneous acid (PandA®) on tree growth, fruit quality and yield were investigated in 'Hass' avocado over two consecutive years.

There are numerous claims often anecdotally that the application of microbial products (often referred to as 'bio-fertilisers") can improve growth, fruit yield and quality in horticultural crops. The effect of TwinN® and BB5® application (formulations of root-colonising nitrogen fixing bacteria) on tree growth, fruit quality and yield in 'Hass' avocado was investigated at three sites.

The effect of branch scoring in autumn on fruit size and yield in avocado was investigated at several sites across Australia. Scoring involved cutting a groove no more than 3mm wide around the branch to sever the phloem using a knife or pruning saw. The effect of scoring on fruit size and yield in vigorous regrowth resulting from stumping trees were also investigated at the Central Queensland site.

In Central Queensland mulching with avocado woodchip significantly increased mean fruit numbers by 18.9% and cumulative yield (kg/tree) by 21.5% in 'Hass' trees over the three years of the trial. Mulching with cane-tops also tended to increase mean fruit numbers (14.8%) and cumulative yield (14.7%). There was a trend towards an increase in feeder root activity in trees mulched with avocado woodchip and cane-tops. Although there was no significant improvement in fruit quality during the course of the trial mulching with filter-press and cane-tops tended to reduce the incidence of fruit rots and disorders in the first year.

In North Queensland there was a trend towards an increase in mean fruit number and yield in ‘Shepard’ and ‘Hass’ trees receiving composted vegetation waste at 10t/ha and an increase in fruit size in trees mulched with compost at 20 t/ha in combination with Rhodes grass hay. There was also a tendency for an increase in root growth activity in all mulched trees at this site.

Soil and foliar application of pyroligneous acid (PandA®) alone during the cropping season had no effect on shoot growth, yield and fruit quality, However when PandA® at 4 ml/L was added to the copper fungicide (in the same tank mix) foliar applications improved fruit quality with a reduction in the incidence of vascular browning, stem end rots and body rots compared with both the untreated control and copper fungicide treated trees.

The application of TwinN® and BB5® (formulations of root-colonising nitrogen fixing bacteria) can increase feeder root activity in ‘Hass’ avocado. This increase in root growth and possible nutrient uptake may be responsible for improvements in shoot growth, tree health and fruit quality observed at some of the experimental sites.

Branch scoring in autumn (April-May) may be a useful strategy to induce cropping in vigorous avocado trees or to control vigour and promote fruiting in regrowth on stumped trees. A significant increase in the number of fruit and yield was observed on the scored branch at six of the eight experimental sites. However due to the increase in fruit numbers mean fruit size was often reduced in the scored branch. This technique is still experimental and may not necessarily work under all growing conditions.

General Introduction

An increase in public awareness and concern for the environment has led to a significant increase in consumer demand for ‘safer’ food and more environmentally sensitive production methods. Australian avocado growers recognise that to remain competitive there are increasing demands to meet consumer expectations, optimise fruit yield and quality, reduce chemical use and develop market opportunities.

Many avocado growers have adopted sustainable orchard management practices including optimising nutritional and irrigation management, reducing pesticide applications, and maintaining a healthy soil and orchard environment. There are also many companies promoting a range of products for use in avocado production including soil and crop health formulations and organic and microbial fertilisers, often with little scientific evaluation.

Several orchard management practices and products are being used by avocado growers including: mulching, natural mineral fertilisers, fish and kelp concentrates, composts teas and other brewed microbes and branch scoring.

The objective of this project was to identify sustainable orchard management practices used by avocado growers across Australia; conduct trials to evaluate the effect of some of these strategies on tree growth, fruit quality and yield; and provide recommendations to the wider industry on the most promising practices.

The selection of orchard management practices evaluated in this project was determined by identifying strategies used by growers across Australia; the availability of product; the suitability of the strategy for use by the wider industry and the willingness of companies to provide product for evaluation on commercial avocado orchards.

1. Effect of mulching on tree growth, yield and fruit quality

1.1 Introduction

Avocado is indigenous to the highland and lowland forests of Mexico and Central America where it has adapted to soils with abundant surface organic litter that provide a well aerated substrate, with a high water holding capacity and rich in microorganisms (Whiley, 2002; Wolstenholme, 2002).

The application of organic mulches has been widely recommended for use in avocado orchards. The benefit of maintaining high levels of organic matter to suppress *Phytophthora cinnamomi* (root rot) activity is well documented (Broadbent and Baker, 1974; Pegg and Whiley, 1987; Turney and Menge, 1994). Mulching has also been reported to increase water and nutrient availability (Gregoriou & Rajkumar, 1984), improve soil structure and porosity (Gallardo-Laro & Nogales, 1987) and help maintain constant soil temperatures (Gregoriou & Rajkumar, 1984).

Mulching has also been shown to promote root growth (Moore-Gordon *et al*., 1996; 1997; Wolstenholme *et al*., 1998; Dixon *et al*., 2007). The prolonged and extensive root growth observed in trees mulched with composted pine bark and the associated amelioration of stress was responsible for the increase in fruit size and yield in 'Hass' grown in subtropical South Africa (Moore-Gordon *et al*., 1996; 1997; Wolstenholme *et al*., 1998).

The aim of this research was to investigate the effect of the mulching over three consecutive years on tree growth, yield and fruit quality in 'Hass' avocado grown in subtropical Central Queensland. Additional mulching trials over one cropping season were also established on 'Shepard' and 'Hass' trees in tropical North Queensland.

1.2 Materials and Methods

1.2.1 Experimental site 1

In September 2009 a trial was established on a commercial orchard near Bundaberg in Central Queensland (latitude 25°S) to investigate the effect of mulching treatments on tree growth, yield and fruit quality. 2½ year old 'Hass' trees were mulched with filter-press (a sugar industry by-product), avocado woodchip and cane-tops to a depth of 5, 10 and 20 cm, respectively. A grower treatment comprising of inter-row slashings with a thin layer of filter-press of less than 2 cm was included for comparison. Mulching treatments were reapplied in September 2010 and 2011.

The trial involved four treatments with seven single tree replications per treatment in a randomised block design.

1.2.1.1 Shoot growth and yield

Shoots were tagged prior to flowering and the effect of mulching on shoot growth (spring and summer flush length) and fruiting was assessed in 10 shoots in seven trees for each treatment. In 2010, 2011 and 2012 trees were harvested on 3 June, 20 June and 18 June, respectively and the number and weight of fruit from each tree was recorded. Average fruit weight was calculated from the data. Cumulative yields were also calculated over the three years

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1.2.1.2 Root growth and tree health

In the 2010/11 cropping season the effect of mulching on root growth was assessed in five trees for each treatment using 'root windows' (A. Whiley, personal communication). Windows were installed in September 2010 by scraping back any mulch, leaf litter and about 1 cm of soil and placing a clear perspex sheet (500 x 500 x 2 mm) on the soil at one site 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. Root growth was assessed on 17 January 2011. The length of the visible non-suberised roots (usually white to light brown) were assessed by removing the mulch and black foam, and tracing the outline of roots visible at the soil-perspex interface onto plastic sheets with a black permanent marker. The root tracings were measured and the total length (metres) of non-suberised roots for each perspex sheet was calculated.

The canopy of each tree was visually rated for tree health according to the Ciba-Geigy scale (Darvas *et al.*, 1984; Bezuidenhout *et al.*, 1987) where 0 = healthy and 10 = dead. Canopy health was assessed at the commencement of the trial in September 2009 and at the completion of the trial after harvest in July 2012.

1.2.1.3 Fruit quality

At harvest 20 fruit of uniform size were sampled from five trees from each treatment and packed directly into single layer trays. A further five fruit per tree were sampled at the time of harvest to determine fruit maturity. A core sample of the flesh was taken from the centre of each fruit using the Hofshi plugger. Samples were diced and weighed before and after drying at 65°C until constant weight (approx. 3 days) and percent dry matter was calculated as follows: (weight of dried avocado sample) / (weight of fresh avocado sample) x 100.

Fruit was ripened at 20°C and fruit quality, including fruit softening, the stage of ripeness, and the severity of diseases and internal disorders was assessed as described in the International Avocado Quality Manual (White *et al*., 2001). Fruit firmness was assessed using gentle hand pressure, and the days to eating soft (DTES) 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 skin colour at ripe was visually rated based on a 1-6 scale (1 = green and 6 = black).

Ripe fruit were 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, stem end rots as those starting from the stem end of the fruit and vascular browning 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. Fruit that had less than 10% of the flesh volume affected by disease and internal disorders were considered to be acceptable. Fruit acceptability was calculated as the percentage of acceptable fruit in relation to the total number of fruit per treatment.

1.2.2 Experimental site 2

Trials investigating the effect of mulching on tree growth and yield were established on a commercial orchard near Mareeba in North Queensland (latitude 17°S) in September 2011. A composted product (derived from vegetation waste), Rhodes grass hay and a combination of the two products were applied to 2½ year old 'Shepard' and 'Hass' avocado trees. Compost was applied at a rate of 10 and 20 tonnes/hectare; Rhodes grass hay at a thickness of 15cm; and in the combined treatments Rhodes grass hay was applied over the top of the compost layer. A grower treatment (inter-row slashings) was included for comparison.

The trial involved six treatments with six single tree replications per treatment in a randomised block design.

1.2.2.1 Shoot growth and yield

In September 2011 shoots were tagged at flowering and the effect of mulching on shoot growth and fruiting was assessed at harvest in 10 shoots in six trees for each treatment. 'Shepard' trees were harvested on 21 February 2012 while 'Hass' trees were harvested on 4 April 2012. The number and weight of fruit from each tree was recorded and average fruit weight was calculated from the data.

1.2.2.2 Flowering, root growth and tree health

The effect of mulching on flowering, root growth, and tree health were assessed on 23 August 2012. Flowering was assessed by visually rating the level of flowering on a 0 to 5 scale where 0 represented no flowering and 5 represented heavy flowering. Root growth was assessed by scraping away the mulch at a single site for each tree equally distant between the trunk and edge of the canopy. This was carried out on the same side of the tree for all trees. The amount of root growth present in a 30cm^2 area of soil was visually rated on a 0 to 5 scale where 0 represented no new roots and 5 represented numerous new roots. Tree health was determined by assessing the percentage of leaf drop at flowering.

1.2.3 Statistical analysis

Statistical analyses were performed using analysis of variance (ANOVA) and the least significant difference (l.s.d.) test at $P \leq 0.05$ was used to separate treatment means.**1.3 Results**

1.3.1 Experimental site 1

1.3.1.1 Shoot growth and yield

In the first year of the trial there was no significant effect of mulching on shoot growth and yield (Table 1).

Table 1 Effect of mulching on shoot growth, percentage of shoots bearing fruit, number of fruit, yield and average fruit weight in 3 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Spring and summer shoot growth was measured in December 2009 and April 2010, respectively. Shoot growth and percentage fruiting data are means of 70 shoots from seven trees per treatment. Trees were harvested in June 2010.Yield data are means of seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Shoot growth (spring + summer) (cm)	% of shoots with fruit	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Grower	40.0 a	31.4 a	58.3 a	15.8 a	292.6 a
Filter-press	39.1 a	28.6 a	42.9 a	12.2 a	289.5 a
Cane-tops	38.2 a	40.0 a	64.3 a	18.1 a	291.5 a
Avocado Woodchip	40.2 a	32.9 a	54.6 a	14.9 a	290.7 a

In the second year of the trial shoot growth was significantly less in trees mulched with avocado woodchip (20.3 cm) and cane-tops (22.2 cm) compared with 27.3 cm in the grower treated trees (Table 2). This reduction in shoot growth was likely to be due to the trend towards a higher percentage of shoots bearing fruit in the avocado woodchip (55.7%) and cane-tops (54.3%) treatments, compared with 38.6% in the grower treated trees. There was also a significant increase in the number of fruit (380) and yield (97.7 kg) in trees mulched with avocado woodchip compared with 259 fruit and 70.5 kg in the grower treated trees (Table 2). Fruit size tended to be smaller in trees mulched with avocado chip due to the increase in the number of fruit. In the third year of the trial there was no significant effect of mulching on shoot growth and yield (Table 3). Cumulative yields over the three years were highest in trees mulched with avocado woodchip (Table 4).

Table 2 Effect of mulching on shoot growth, percentage of shoots bearing fruit, number of fruit, yield and average fruit weight in 4 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Spring and summer shoot growth was measured in December 2010 and April 2011, respectively. Shoot growth and percentage fruiting data are means of 70 shoots from seven trees per treatment. Trees were harvested in June 2011.Yield data are means of seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Shoot growth (spring + summer) (cm)	% of shoots with fruit	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Grower	27.3 a	38.6 a	259 b	70.5 b	276.2 a
Filter-press	24.0 ab	37.1 a	281 b	78.1 b	277.1 a
Cane-tops	22.2 b	54.3 a	317 b	84.4 ab	268.3 a
Avocado Woodchip	20.3 b	55.7 a	380 a	97.7 a	258.4 a

Table 3 Effect of mulching on shoot growth, percentage of shoots bearing fruit, number of fruit, yield and average fruit weight in 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Spring and summer shoot growth was measured in December 2011 and April 2012, respectively. Shoot growth and percentage fruiting data are means of 70 shoots from seven trees per treatment. Yield data are means of seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Shoot growth (spring + summer) (cm)	% of shoots with fruit	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Grower	25.3 a	31.4 a	297 a	51.6 a	177.5 a
Filter-press	24.5 a	32.9 a	276 a	48.6 a	179.6 a
Cane-tops	24.2 a	35.7 a	324 a	55.6 a	176.8 a
Avocado Woodchip	23.8 a	34.3 a	295 a	55.0 a	187.5 a

Table 4 Effect of mulching on the cumulative number of fruit and yield and average fruit weight from 2010 to 2012 in 'Hass' avocado trees near Bundaberg in Central Queensland. Data are means of seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Grower	614 b	137.9 b	228.3 a
Filter-press	601 b	138.9 b	234.3 a
Cane-tops	705 ab	158.2 ab	227.2 a
Avocado woodchip	730 a	167.6 a	231.5 a

1.3.1.2 Root growth and tree health

Although there was no significant effect of mulching on root growth measured in the second year of the trial, there was a trend towards an increase in the length of non-suberised roots in trees mulched with avocado woodchip and cane-tops with 4.7m and 4.6m, respectively compared with 2.5m and 2.4m in the filter press and grower treated trees.

At the commencement of the trial in September 2009 average tree health rating ranged from 1.6 to 1.9 (on the Ciba-Geigy scale where 0 = healthy and 10 = dead) and after three years of mulching ranged from 2.7 to 3.3 with no significant statistical difference between treatments.

1.3.1.3 Fruit quality

There was no consistent effect of mulching on fruit maturity (% DM) at the time of harvest (Table 5). In 2010 fruit harvested from trees mulched with filter-press had a significantly higher % DM, while in 2012 it was significantly lower when compared with the grower treated trees. % DM was lowest in trees mulched with cane-tops in 2010 and 2011.

Table 5 Effect of mulching on maturity (% DM) of fruit harvested from 'Hass' avocado trees near Bundaberg in Central Queensland in June 2010, 2011 and 2012. Values are means of 25 fruit from five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	2010	2011	2012
Grower	26.9 b	28.2 ab	29.4 a
Filter-press	27.4 a	28.5 a	28.7 b
Cane-tops	26.2 c	27.9 b	29.6 a
Avocado woodchip	26.8 b	28.4 a	29.1 ab

Fruit ripening (days to eating soft) was significantly affected by mulching treatment in each year of the experiment (Table 6). In 2010, fruit sampled from trees mulched with cane-tops and in 2011, fruit sampled from trees mulched with cane-tops and avocado woodchip took significantly longer to ripen. In contrast, fruit sampled from the grower treatment was found to take significantly longer to reach the eating soft stage in 2012. In 2011 and 2012 the skin colour rating was significantly lower in fruit sampled from the grower treated trees (Table 6).

Table 6 Effect of mulching on ripening (days to eating soft) and skin colour in fruit harvested from 'Hass' avocado trees near Bundaberg in Central Queensland in June 2010, 2011 and 2012. Fruit skin colour was visually rated on a 1-6 scale where 1 = green and 6 = black. Values are means of 100 fruit sampled from five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Days to eating soft			Skin colour		
	2010	2011	2012	2010	2011	2012
Grower	8.6 b	11.9 b	12.8 a	5.5 a	4.5 c	4.8 c
Filter-press	8.4 b	11.9 b	12.2 b	5.7 a	4.8 a	4.9 bc
Cane-tops	9.3 a	12.8 a	12.0 b	5.5 a	4.6 bc	5.0 ab
Avocado woodchip	8.6 b	12.6 a	11.9 b	5.6 a	4.7 ab	5.0 a

The effect of mulching on the severity (% of flesh affected) of fruit rots and disorders over the three years of the trial is presented in Table 7. In 2010 mulching with cane-tops tended to reduce the severity of stem end rots and body rots with 3.3 and 4.5% of the flesh volume affected, respectively compared with 4.5 and 6.6% in the grower treated trees. In 2011 the severity of vascular browning, stem end rots and body rots was least in trees mulched with avocado woodchip with 1.5, 1.7 and 0.5% of the flesh volume affected, respectively compared with 1.8, 2.0 and 1.0% in the grower treated trees. While in 2012 the severity of vascular browning, stem end rots and body rots was least in trees mulched with cane-tops with 2.7, 2.7 and 1.1% of the flesh volume affected compared with 3.3, 3.4 and 1.9% in the grower treated trees.

Table 7 Effect of mulching on the severity (% of flesh volume affected) of body rots, stem end rots and vascular browning in fruit harvested from 'Hass' avocado trees near Bundaberg in Central Queensland in June 2010, 2011 and 2012. Fruit was ripened at 20ºC. Values are the means of 100 fruit from five trees per treatment.

	2010			2011			2012		
Treatment	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots
Grower	3.6	4.5	6.6	1.8	2.0	1.0	3.3	3.4	1.9
Filter-press	2.4	3.4	5.3	1.8	2.2	1.1	3.4	3.4	2.1
Cane-tops	2.8	3.3	4.5	1.9	2.2	0.8	2.7	2.7	1.1
Avocado woodchip	2.7	3.4	5.7	1.5	1.7	0.5	3.0	3.0	1.4
Mean	2.9	3.6	5.5	1.7	2.0	0.8	3.1	3.1	1.6

Due to the non-normality of the severity data the effect of mulching on fruit quality was statistically analysed by comparing the incidence (% of fruit affected) of fruit rots and disorders. There was no significant effect of mulching on the incidence of fruit rots and disorders during the trial (Table 8). However, in 2010 mulching with filter-press tended to reduce the incidence of vascular browning and stem end rots with 9 and 14% of the fruit having at least 10% of the flesh affected compared with 20 and 21% of the fruit in the grower treated trees. While mulching with cane-tops tended to reduce the incidence of body rots with 13% of the fruit having at least 10% of the flesh affected compared with 36% in the grower treated trees.

There was also no significant effect of mulching on the percentage of acceptable fruit (% of fruit with less than 10% of the flesh affected by rots and disorders) (Table 9). However in 2010 there tended to be less acceptable fruit in the grower treated trees with 42% compared with 52-56% in the mulched trees.

Table 8 Effect of mulching on the incidence of vascular browning, stem end rots and body rots in fruit harvested from 'Hass' avocado trees near Bundaberg in Central Queensland in June 2010, 2011 and 2012. Fruit was ripened at 20ºC. Values represent the percentage of fruit with at least 10% of the flesh affected and are the means of 100 fruit from five trees per treatment. Means within columns with the same letter are not significantly different (*P* < 0.05).

	2010			2011			2012		
Treatment	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots
Grower	20 a	21 a	36 a	7 a	9 a	3 a	17 a	19 a	9 a
Filter-press	9 a	14 a	29 a	6 a	10 a	4 a	17 a	18 a	10 a
Cane-tops	12 a	17 a	13 a	5 a	11 a	1 a	15 a	16 a	3 a
Avocado woodchip	12 a	17 a	28 a	6 a	10 a	2 a	14 a	14 a	5 a

Table 9 Effect of mulching on the percentage of acceptable fruit harvested from 'Hass' avocado trees near Bundaberg in Central Queensland in June 2010, 2011 and 2012. Fruit was ripened at 20ºC. Values represent the percentage of fruit with less than 10% of the flesh affected by rots and disorders and are the means of 100 fruit from five trees per treatment. Means within columns with the same letter are not significantly different (*P* < 0.05).

Treatment	2010	2011	2012
Grower	42 a	75 a	57 a
Filter-press	52 a	74 a	59 a
Cane-tops	56 a	76 a	64 a
Avocado woodchip	53 a	82 a	61 a

1.3.2 Experimental site 2

1.3.2.1 Shoot growth and yield

In 'Shepard' trees there was no significant effect of mulching on shoot growth and percentage of shoots bearing fruit (Table 10). However there tended to be more fruit and a greater yield (kg/tree) in trees receiving compost at a rate of 10 t/ha. Fruit size tended to be larger in trees receiving the higher rate of compost (20 t/ha) and in the combined Rhodes grass hay and compost treatments.

There was also no significant effect of mulching on shoot growth and percentage of shoots bearing fruit in 'Hass' trees (Table 11). However there was a trend towards more fruit and a greater yield (kg/tree) in trees receiving compost at a rate of 10 t/ha. Fruit size tended to be largest in trees receiving the higher rate of compost (20 t/ha) in combination with Rhodes grass hay with a mean fruit weight of 307.1g compared with 273.8g in the grower treated control trees.

Table 10 Effect of mulching on shoot growth, percentage of shoots bearing fruit, number of fruit, yield and average fruit weight in 3 year old 'Shepard' avocado trees near Mareeba in North Queensland. Shoot assessments were made in February 2012. Shoot growth and percentage fruiting data are means of 60 shoots from six trees per treatment. Trees were harvested in February 2012. Yield data are means of six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Shoot growth (cm)	% of flowering shoots with fruit	No. of fruit	Yield (kg/tree)	Av. fruit wt (g)
Grower	16.3 a	60.0 a	149 a	35.5 a	245.4 a
Rhodes grass hay	16.1 a	68.3 a	187 a	44.8 a	242.1 a
Compost (10 t/ha)	16.7 a	65.0 a	207 a	48.7 a	240.5 a
Rhodes grass hay + compost (10 t/ha)	18.2 a	61.7 a	150 a	37.1 a	252.6 a
Compost (20 t/ha)	16.3 a	60.0 a	154 a	38.1 a	253.4 a
Rhodes grass hay + compost (20 t/ha)	17.2 a	70.0 a	154 a	39.2 a	254.9 a

Table 11 Effect of mulching on shoot growth, percentage of shoots bearing fruit, number of fruit, yield and average fruit weight in 3 year old 'Hass' avocado trees near Mareeba in North Queensland. Shoot assessments were made in April 2012. Shoot growth and percentage fruiting data are means of 60 shoots from six trees per treatment. Trees were harvested in April 2012. Yield data are means of six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Shoot growth (cm)	% of flowering shoots with fruit	No. of fruit	Yield (kg/tree)	Av. fruit wt (g)
Grower	33.3 a	35.0 a	51 a	13.8 a	273.8 a
Rhodes grass hay	32.4 a	31.7 a	46 a	13.5 a	296.2 a
Compost (10 t/ha)	30.9 a	43.3 a	75 a	20.3 a	274.6 a
Rhodes grass hay + compost (10 t/ha)	30.1 a	35.0 a	60 a	16.5 a	289.8 a
Compost (20 t/ha)	31.4 a	36.7 a	58 a	15.6 a	284.8 a
Rhodes grass hay + compost (20 t/ha)	32.2 a	33.3 a	52 a	15.3 a	307.1 a

1.2.2.2 Flowering, root growth and tree health

Mulching tended to increase flowering and root growth in both 'Shepard' and 'Hass' trees (Table 12 and Table 13, respectively). There was no significant effect of mulching on tree health, however 'Hass' trees mulched with the high rate of compost in combination with Rhodes grass hay tended to have less leaf drop with 33% compared with 43% in grower treated trees.

Table 12 Effect of mulching on flowering, root growth and percentage leaf drop in 3½ year old 'Shepard' avocado trees near Mareeba in North Queensland. Assessments were made in August 2012. Flowering was rated on a 0 to 5 scale where 0 represented no flowering and 5 represented heavy flowering. Root growth was rated on a 0 to 5 scale where 0 represented no new roots and 5 represented numerous new roots. Values are means of six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Flowering	Root growth	Leaf drop (%)
Grower	4.3 b	1.8 a	32.5 a
Rhodes grass hay	4.8 a	3.0 a	34.2 a
Compost (10 t/ha)	4.5 ab	2.8 a	36.7 a
Rhodes grass hay + compost (10 t/ha)	4.5 ab	2.5 a	38.3 a
Compost (20 t/ha)	4.8 a	3.0 a	32.5 a
Rhodes grass hay + compost (20 t/ha)	4.8 a	2.5 a	31.7 a

Table 13 Effect of mulching on flowering, root growth and percentage leaf drop in 3½ year old 'Hass' avocado trees near Mareeba in North Queensland. Assessments were made in August 2012. Flowering was rated on a 0 to 5 scale where 0 represented no flowering and 5 represented heavy flowering. Root growth was rated on a 0 to 5 scale where 0 represented no new roots and 5 represented numerous new roots. Values are means of six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Flowering	Root growth	Leaf drop (%)
Grower	2.8 a	1.8 a	43.3 a
Rhodes grass hay	3.7 a	2.3 a	46.7 a
Compost (10 t/ha)	4.7 a	2.3 a	46.7 a
Rhodes grass hay + compost (10 t/ha)	4.2 a	2.3 a	43.3 a
Compost (20 t/ha)	3.7 a	2.3 a	42.5 a
Rhodes grass hay + compost (20 t/ha)	3.5 a	2.8 a	33.3 a

1.4 Discussion

In subtropical Central Queensland mulching with avocado woodchip increased mean fruit numbers by 18.9% and increased cumulative yield (kg/tree) by 21.5% in 'Hass' trees over the three years of the trial. Mulching with cane-tops also tended to increase mean fruit numbers (14.8%) and cumulative yield (14.7%). These cumulative outcomes were due to significant increases in fruit number and yield in the second year of the trial. There was also a trend towards an increase in feeder root activity. Trees mulched with avocado woodchip and cane-tops had 4.7m and 4.6m of new root growth in a $50cm^2$ window at the soil/mulch interface compared with 2.4m in control trees in the second year of the trial. Although there was no significant improvement in fruit quality during the course of the trial mulching with filter-press tended to reduce the incidence of vascular browning and stem end rots, and mulching with cane-tops tended to reduce the incidence of body rots in the in the first year.

In tropical North Queensland there was a trend towards an increase in mean fruit number and yield in 'Shepard' and 'Hass' trees receiving composted vegetation waste at 10t/ha and an increase in fruit size in trees mulched with compost at 20 t/ha in combination with Rhodes grass hay. There was also a tendency for an increase in root growth activity in all mulched trees at this site.

The 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% in subtropical South Africa (Moore-Gordon *et al*., 1996; 1997 and Wolstenholme *et al*., 1998). These improvements in tree performance were attributed 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 naturally high organic matter soils of New Zealand the increase in feeder root activity observed at the soil/mulch interface in mulched trees did not result in an increase in fruit size and yield (Dixon *et al*., 2007).

The benefit of maintaining high levels of organic matter to suppress *Phytophthora cinnamomi* (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; Turney and Menge, 1994). There was no significant effect of mulching on tree health observed in the current trials. However, leaf drop at flowering as an indicator of stress tended to be less in 'Hass' trees mulched with compost at 20 t/ha in combination with Rhodes grass hay at the North Queensland site.

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).

In areas that experience heavy summer rainfall, the time of application is important (Wolstenholme *et al*., 1996) as thick mulches can be too moisture retentive thus exacerbating root rot problems. In North Queensland mulching treatments were applied at flowering in September prior to the commencement of the summer dominated rainfall period from December to March. Applying mulches after harvest (March in 'Shepard' and April in 'Hass') may eliminate any potential water-logging issues.

At the Central Queensland site well above average rainfall experienced during the 2011/12 cropping season not only impacted on tree health (due to water-logging and Phytophthora issues) but also reduced mean fruit size (180.4 g) and average yield (52.7 kg/tree) across all treatments compared with 270.0g and 82.7 kg/tree in the 2010/11 cropping season. Although there were no significant differences in fruit size and yield in the 2011/12 cropping season between treatments the ability of mulches to retain more water (particularly during increased rainfall events) may have negated any potential improvements in root growth, fruit size and yield in the mulched trees.

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

2. Effect of pyroligneous acid (PandA®) on tree growth, yield and fruit quality

2.1 Introduction

Pyroligneous acid is a light brown coloured organic liquid produced by heating Moso bamboo to 250-350°C in a restricted oxygen kiln, where the liquids and oils in the plant cells of the bamboo are turned into gaseous vapours. These vapours pass through several condensers where they are cooled and turned back into liquids. The solid residual is Moso Bio-Char. The condensed liquid is further refined into three fractions. The heavy tars and oils settle to the bottom, the pyroligneous acid is the middle fraction, while the low density light oils accumulate on the top. After separation it is aged for at least six months before further decanting prior to packing. Pyroligneous acid has a density of 1.01 and a pH of 2.4-2.8. There are traces of more than 200 organic components that can be grouped as phenolics (18-21% of total organic chemicals), aldehyde (3-5%), keytones (8-17%), alcohol (2-7%) and esters (1-1.5%). It also contains sodium 3.1mg/kg, magnesium 2.9mg/kg, calcium 56mg/kg, iron 13mg/kg and zinc 0.9mg/kg.

Pyroligneous acid has been reported to improve root, shoot and fruit growth, increase resistance to pests and diseases, reduce leaf fall and fruit drop, and improve yield and fruit quality in several crops. The aim of this research was to identify the effect of soil and foliar applications of pyroligneous acid (PandA®) on tree growth, fruit quality and yield in 'Hass' avocado.

2.2 Materials and Methods

2.2.1 Trees and treatments

In 2010 a preliminary trial investigating the effect of foliar application of pyroligneous acid (PandA®) on fruit quality and yield was established on 2½ year old 'Hass' trees in a commercial orchard near Bundaberg in Central Queensland (latitude 25°S). PandA® at 2 and 4 ml/L was applied at 3-5 week intervals using a motorised, backpack spray unit. Five trees for each treatment were sprayed to the point of run-off using 2.5 litres per tree (500 L/ha). A total of six applications were made during the cropping season with the first application on the 21 January 2010 and additional treatments on the 17 February, 18 March, 7 April and 17 May. The final treatment was applied one week prior to harvest on 3 June 2010. It is important to note the pyroligneous acid treatments were in addition to the grower's disease control measures which consisted of six copper fungicide (Norshield® WG at 1.05 g/L containing 750 g/kg copper as cuprous oxide) applications during the cropping season from October 2009 to May 2010.

The preliminary trial involved three treatments with five single tree replications per treatment in a completely randomised design. The treatments used include:

1. Copper fungicide only (Norshield® at1.05 g/L)
2. Copper fungicide + foliar applied PandA® at 2 ml/L
3. Copper fungicide + foliar applied PandA® at 4 ml/L

In 2011 a trial to investigate the effect of soil and foliar applications of pyroligneous acid (PandA®) on fruit quality and yield was established on 3½ year old 'Hass' trees. Soil and foliar treatments of PandA® either alone or in combination with a copper fungicide (Norshield®) were applied at 3-5 week intervals. Soil treatments were applied as a drench at a rate of 12 litres per tree to a 2m^2 area around the tree trunk. Foliar treatments were applied using a motorised spray unit to the point of run-off using six litres per tree (1200 L/ha). A total of six applications were made during the cropping season with the first application on 18 January 2011 and additional treatments on the 14 February, 21 March, 25 April and 27 May. The final treatment was applied one week prior to harvest on 15 June 2011. An unsprayed control and copper fungicide treatment (Norshield® at 1.05 g/L) was included for comparison. All trees received three copper fungicide treatments between October and December 2010 prior to the commencement of this trial.

In the 2011/12 cropping season the trial was repeated. A total of seven applications were made with the first application on 26 October 2011 and additional treatments on the 22 November, 9 January, 3 February, 12 March and 20 April. The final treatment was applied one week prior to harvest on 15 May 2012. All trees received one copper fungicide treatment in October 2011 prior to the commencement of this trial.

The trial involved eight treatments with five single tree replications per treatment in a randomised block design. The treatments used include:

1. Untreated (Control)
2. Copper fungicide (Norshield® at1.05 g/L)
3. Foliar applied PandA® at 2 ml/L
4. Copper fungicide + foliar applied PandA® at 2 ml/L
5. Foliar applied PandA® at 4 ml/L
6. Copper fungicide + foliar applied PandA® at 4 ml/L
7. Soil applied PandA® at 4 ml/L
8. Copper fungicide + soil applied PandA® at 4 ml/L

2.2.2 Shoot growth and yield

In 2010 trees were harvested on 10 June and the number and weight of fruit was recorded in five trees for each treatment.

In the 2011/12 cropping season the effect of soil and foliar treatments on shoot growth (spring and summer flush length) was assessed in 10 fruiting and 10 non-fruiting shoots in five trees for each treatment. In 2011 and 2012 trees were harvested by the 24 June and 6 June, respectively and the number and weight of fruit from each tree was recorded. Average fruit weight was calculated from the data. Cumulative yields were also calculated over the two years.

2.2.3 Fruit quality

At harvest 20 fruit of uniform size were sampled from five trees from each treatment and ripened at 20°C. In 2010, 2011 and 2012 fruit was sampled one week after the final treatment on the 10 June, 22 June and 22 May, respectively. In 2011 and 2012 a further five fruit per tree were sampled at the time of harvest to determine fruit maturity. Percentage dry matter was determined as described earlier (section 1.2.1.2).

At the eating soft stage fruit were visually rated for the severity of rots and internal disorders as described earlier (section 1.2.1.2). The effect of treatment on the severity (% of flesh affected) and incidence (% of fruit affected) of fruit rots and disorders were determined.

2.2.4 Shoot and tree health

The effect of soil and foliar treatments on shoot and tree health was assessed after harvest in July 2012. Shoot health was assessed by counting the number of flushes that were clean (no presence of sooty blotch) in 10 shoots in five trees of each treatment.

The canopy of each tree was visually rated for tree health according to the Ciba-Geigy scale (Darvas *et al.*, 1984; Bezuidenhout *et al.*, 1987) where 0 = healthy and 10 = dead. Canopy health was assessed at the commencement of the trial in January 2011 and at the completion of the trial after harvest in July 2012.

2.2.5 Statistical analysis

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

2.3 Results

2.3.1 Shoot growth and yield

In the 2010 cropping season there was no effect of pyroligneous acid on yield with a mean of 13.9 and 12.7 kg/tree produced in the 2 ml/L and 4 ml/L PandA® treatments respectively, compared with 13.8 kg in trees receiving copper fungicide only.

In the 2011/12 cropping season there was no significant effect of pyroligneous acid on shoot growth (Table 1). In 2011 and 2012 there was no significant effect of pyroligneous acid on the number of fruit, yield and average fruit weight (Table 2) and cumulative yields over the two years (Table 3).

Table 1 Effect of pyroligneous acid (PandA®) on shoot growth in fruiting and non-fruiting shoots in 4 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Spring and summer shoot growth was measured in December 2011 and April 2012, respectively. Shoot growth data are means of 50 shoots from five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Fruiting shoot length (cm)	Non-fruiting shoot length (cm)
Untreated (Control)	9.1 a	26.4 a
Copper fungicide (Norshield® 1.05 g/L)	8.7 a	25.9 a
Foliar PandA® 2 ml/L	9.4 a	25.8 a
Copper + foliar PandA® 2 ml/L	8.8 a	25.9 a
Foliar PandA® 4 ml/L	9.7 a	26.1 a
Copper + foliar PandA® 4 ml/L	10.3 a	26.4 a
Soil PandA® 4 ml/L	9.6 a	27.2 a
Copper + soil PandA® 4 ml/L	9.2 a	25.8 a

Table 2 Effect of pyroligneous acid (PandA®) on the number of fruit, yield and average fruit weight in 4 and 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Trees were harvested by 24 June in 2011 and by 6 June in 2012. Data are means of five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	2011			2012		
	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)	No. of fruit	Yield (kg/tree)	Av. fruit wt (g)
Untreated (Control)	184 a	51.2 a	284.6 a	392 a	57.0 a	145.8 a
Copper fungicide (Norshield® 1.05g/L)	228 a	63.2 a	279.1 a	396 a	59.5 a	146.0 a
Foliar PandA® 2 ml/L	193 a	53.5 a	281.8 a	397 a	57.0 a	152.2 a
Copper + foliar PandA® 2 ml/L	195 a	54.0 a	281.5 a	344 a	50.4 a	145.3 a
Foliar PandA® 4 ml/L	219 a	61.3 a	280.0 a	448 a	65.8 a	147.3 a
Copper + foliar PandA® 4 ml/L	204 a	57.6 a	281.5 a	398 a	61.0 a	155.5 a
Soil PandA® 4 ml/L	205 a	55.7 a	277.4 a	389 a	55.6 a	146.3 a
Copper + soil PandA® 4 ml/L	184 a	51.7 a	279.3 a	410 a	62.1 a	148.5 a

Table 3 Effect of pyroligneous acid (PandA®) on the cumulative number of fruit and yield and average fruit weight in 'Hass' avocado trees near Bundaberg in Central Queensland. Trees were harvested by 24 June in 2011 and by 6 June in 2012. Data are means of five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Untreated (Control)	575 a	108.1 a	187.4 a
Copper fungicide (Norshield® 1.05g/L)	624 a	122.8 a	197.6 a
Foliar PandA® 2 ml/L	590 a	110.5 a	192.6 a
Copper + foliar PandA® 2 ml/L	539 a	104.4 a	194.3 a
Foliar PandA® 4 ml/l	667 a	127.1 a	192.9 a
Copper + foliar PandA® 4 ml/L	602 a	118.6 a	199.6 a
Soil PandA® 4 ml/L	594 a	111.3 a	188.9 a
Copper + soil PandA® 4 ml/L	594 a	113.8 a	192.2 a

2.3.2 Fruit quality

In the preliminary trial the addition of PandA® at 4 m/L tended to improve fruit quality with a reduction in the severity of vascular browning by 1.6%, stem end rots by 1.9% and body rots by 1.3% (Table 4). Due to the non-normality of the severity data the effect of treatment on fruit quality was statistically analysed by comparing the incidence (% of fruit affected) of fruit rots and disorders. The addition of PandA® at 4 m/L significantly reduced the incidence of vascular browning by 16.6% and stem end rots by 6.7% compared with the copper fungicide treatment alone (Table 4).

Table 4 Effect of pyroligneous acid (PandA®) on the severity and incidence of vascular browning, stem end rots and body rots in fruit ripened at 20ºC. Fruit was sampled from 3 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 3 June 2010. Severity values represent the percentage of flesh affected and incidence values represent the percentage of fruit with at least 10% of the flesh affected. Values are the means of 100 fruit from five trees per treatment. Means within columns with the same letter are not significantly different (P < 0.05).

Treatment	Severity			Incidence		
	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots
Copper fungicide (Norshield® 1.05g/L)	4.1	5.1	7.0	23.3 a	25.0 ab	36.7 a
Copper + foliar PandA® 2 ml/L	3.4	5.3	5.1	18.3 ab	33.0 a	26.7 a
Copper + foliar PandA® 4 ml/L	2.5	3.2	5.7	6.7 b	18.3 b	30.0 a

In 2011 and 2012 there was no significant difference in fruit maturity at harvest (% DM) among treatments (Table 5). In 2011 fruit sampled from the copper fungicide and copper + foliar PandA® at 2 and 4 ml/L treatments took significantly longer to ripen (days to eating soft) than the untreated trees (Table 5). There was no significant effect of treatment on fruit ripening in the 2012 cropping season. In 2011 and 2012 the skin colour rating was lowest in fruit sampled from the copper + foliar PandA® at 4 ml/L treated trees (Table 5).

Table 5 Effect of pyroligneous acid (PandA®) on maturity (% DM), ripening (days to eating soft) and skin colour in fruit sampled from 4 and 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 22 June 2011 and 22 May 2012, respectively. % DM values are means of 25 fruit sampled from five trees per treatment. Fruit was ripened at 20°C. Fruit skin colour was visually rated on a 1-6 scale where 1 = green and 6 = black. Fruit ripening and skin colour values are means of 100 fruit sampled from five trees per treatment. Means within columns with the same letter are not significantly different (P < 0.05).

Treatment	% DM		Days to eating soft		Skin colour	
	2011	2012	2011	2012	2011	2012
Untreated (Control)	29.2 a	26.6 a	11.3 b	15.0 ab	5.2 a	4.9 b
Copper fungicide (Norshield® 1.05g/L)	28.8 a	27.9 a	12.1 a	15.0 ab	5.0 c	4.9 b
Foliar PandA® 2 ml/L	29.0 a	26.7 a	11.1 b	14.9 b	5.2 ab	5.1 a
Copper + foliar PandA® 2 ml/L	28.8 a	27.8 a	12.0 a	15.3 a	4.9 cd	4.9 b
Foliar PandA® 4 ml/L	29.5 a	27.0 a	11.4 b	15.3 a	5.1 c	4.9 b
Copper + foliar PandA® 4 ml/L	29.8 a	27.5 a	11.9 a	14.9 b	4.8 d	4.8 c
Soil PandA® 4 ml/L	29.7 a	27.4 a	11.4 b	15.3 a	5.1 bc	5.0 b
Copper + soil PandA® 4 ml/L	29.4 a	27.2 a	11.3 b	15.2 ab	5.1 bc	4.9 b

The effect of soil and foliar application of pyroligneous acid on the severity (% of flesh affected) of fruit rots and disorders in fruit harvested in 2011 and 2012 is presented in Table 6. In 2011 and 2012 soil and foliar applications of PandA® alone at 2 and 4 ml/L had no effect on fruit quality compared with the untreated control. In 2011 there was no improvement in fruit quality when PandA® was included with the copper fungicide treatment compared with copper alone. In 2012 the severity of vascular browning, stem end rots and body rots was least in trees that received foliar PandA® at 4 ml/L + copper with 2.5, 2.3 and 0.7% of the flesh affected, respectively compared with 6.1, 6.2 and 2.6% in the untreated trees.

Table 6 Effect of pyroligneous acid (PandA®) on the severity (% of flesh affected) of vascular browning, stem end rots and body rots in fruit ripened at 20ºC. Fruit was sampled from 4 and 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 22 June 2011 and 22 May 2012, respectively. Values are the means of 100 fruit from five trees per treatment.

Treatment	Severity 2011			Severity 2012		
	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots
Untreated (Control)	2.3	3.3	2.2	6.1	6.2	2.6
Copper fungicide (Norshield® 1.05g/L)	1.6	2.1	1.6	4.2	4.0	1.3
Foliar PandA® 2 ml/L	2.0	3.0	1.9	5.4	5.7	2.0
Copper + foliar PandA® 2 ml/L	1.2	1.7	1.4	3.0	2.8	1.1
Foliar PandA® 4 ml/L	2.2	3.1	1.6	4.9	4.9	1.6
Copper + foliar PandA® 4 ml/L	1.4	2.1	1.3	2.5	2.3	0.7
Soil PandA® 4 ml/L	1.9	2.3	1.3	5.7	5.6	2.2
Copper + soil PandA® 4 ml/L	1.3	1.9	1.5	4.2	4.1	1.5

Due to the non-normality of the severity data the effect of treatment on fruit quality was statistically analysed by comparing the incidence (% of fruit affected) of fruit rots and disorders. In 2011 there was no significant effect of soil and foliar application of pyroligneous acid on the incidence of fruit rots and disorders (Table 7). However, in 2012 foliar application of PandA® at 4 ml/L in combination with copper significantly reduced the incidence of vascular browning, stem-end rots and body rots with 10, 10 and 0% of the fruit having at least 10% of the flesh affected, respectively compared with 34, 34 and 11% of the fruit in the untreated trees (Table 7).

There was a significantly higher percentage of acceptable fruit (% of fruit with less than 10% of the flesh affected by rots and disorders) in trees receiving copper treatment alone or in combination with soil and foliar PandA® in 2011 (Table 8). While in 2012 there was significantly more acceptable fruit in trees receiving foliar application of PandA® at 4 ml/L in combination copper with 72% compared with 42% in the untreated trees (Table 8).

Table 7 Effect of pyroligneous acid (PandA®) on the incidence of vascular browning, stem end rots and body rots in fruit ripened at 20ºC. Fruit was sampled from 4 and 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 22 June 2011 and 22 May 2012, respectively. Values represent the percentage of fruit with at least 10% of the flesh affected and are the means of 100 fruit from five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Incidence 2011			Incidence 2012		
	Vascular browning	Stem end rots	Body rots	Vascular browning	Stem end rots	Body rots
Untreated (Control)	8 a	21 a	10 a	34 a	34 a	11 a
Copper fungicide (Norshield® 1.05g/L)	4 a	14 a	6 a	27 ab	25 ab	5 bc
Foliar PandA® 2 ml/L	7 a	16 a	7 a	33 a	34 a	10 ab
Copper + foliar PandA® 2 ml/L	2 a	10 a	5 a	16 bc	14 bc	5 bc
Foliar PandA® 4 ml/L	5 a	17 a	8 a	25 abc	26 ab	7 ab
Copper + foliar PandA® 4 ml/L	6 a	13 a	5 a	10 c	10 c	0 c
Soil PandA® 4 ml/L	9 a	10 a	5 a	30 ab	30 a	10 ab
Copper + soil PandA® 4 ml/L	3 a	10 a	5 a	25 abc	23 ab	6 ab

Table 8 Effect of pyroligneous acid (PandA®) on the percentage of acceptable fruit harvested from 'Hass' avocado trees near Bundaberg in Central Queensland on 22 June 2011 and 22 May 2012, respectively. Fruit was ripened at 20ºC. Values represent the percentage of fruit with less than 10% of the flesh affected by rots and disorders and are the means of 100 fruit from five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	2011	2012
Untreated (Control)	64 b	42 bc
Copper fungicide (Norshield® 1.05g/L)	80 a	61 ab
Foliar PandA® 2 ml/L	73 ab	50 bc
Copper + foliar PandA® 2 ml/L	84 a	61 ab
Foliar PandA® 4 ml/L	65 b	52 bc
Copper + foliar PandA® 4 ml/L	81 a	72 a
Soil PandA® 4 ml/L	81 a	41 c
Copper + soil PandA® 4 ml/L	80 a	59 abc

2.3.3 Shoot and tree health

The effect of soil and foliar treatments on shoot and tree health is presented in Table 9. Application of PandA® had no significant effect on shoot and tree health. Shoot health as measured by the number of clean growth flushes was significantly improved in trees receiving the copper fungicide treatment. Although there was no significant difference in the rating of tree health (using the Ciba-Geigy scale where 0 = healthy and 10 = dead) there was a trend for trees to be healthier when receiving the copper fungicide treatment.

Table 9 Effect of pyroligneous acid (PandA®) on shoot and tree health in 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Shoot and tree health assessments were made after harvest in July 2012. Shoot health was assessed by counting the number of clean growth flushes. Tree health was rated using the Ciba-Geigy scale where 0 = healthy and 10 = dead. Shoot health values are means of 50 shoots from five trees per treatment. Tree health values are means from five trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Shoot health (No. of clean flushes)	Tree health (0 – 10)	
		Jan 2011	July 2012
Untreated (Control)	1.1 b	1.8 a	4.0 a
Copper fungicide (Norshield® 1.05g/L)	2.1 a	1.6 a	2.8 a
Foliar PandA® 2 ml/L	1.3 b	1.8 a	3.6 a
Copper + foliar PandA® 2 ml/L	2.0 a	1.4 a	3.0 a
Foliar PandA® 4 ml/L	1.2 b	1.6 a	3.4 a
Copper + foliar PandA® 4 ml/L	2.0 a	1.6 a	2.8 a
Soil PandA® 4 ml/L	1.0 b	1.8 a	3.8 a
Copper + soil PandA® 4 ml/L	2.1 a	1.6 a	3.0 a

2.4 Discussion

The results of these trials demonstrate that applications of pyroligneous acid alone during the cropping season had no effect on shoot growth, yield and fruit quality, However when PandA® at 4 ml/L was added to the copper fungicide (in the same tank mix) foliar applications improved fruit quality with a reduction in the incidence of vascular browning, stem end rots and body rots compared with both the untreated control and copper fungicide treated trees.

Applications of pyroligneous acid (PA) at low concentrations have been reported to increase germination, growth and yield in a wide range of plants (Kadota *et al*., 2002; Zulkarami *et al*., 2011). PA contains phenolic compounds that are known to have antimicrobial properties (Loo *et al*., 2008) and have been reported to reduce the growth of phytopathogenic fungi such as *Fusarium*, *Pythium* and *Rhizoctonia*. Jung (2007) demonstrated that PA could inhibit the growth of *Alternaria mali* which is known to cause Alternaria blotch in apple plants.

Further work is required to test the effectiveness of pyroligenous acid application as a possible soil drench on *Phytophthora* root rot and other soil borne diseases that affect avocado.

3. Effect of microbial products on tree growth, yield and fruit quality

3.1 Introduction

There are numerous claims often anecdotally that the application of microbial products (often referred to as 'bio-fertilisers") can improve growth, fruit yield and quality in horticultural crops.

TwinN® and BB5® are freeze dried microbial products used for improving crop productivity. The microbes can be applied to the foliage or to the root system. After application these microbes multiply to exist within the plant foliage, stem and roots as endophytes and also colonise the soil zone in close proximity to the roots. The microbes are Diazotrophs which are able to fix atmospheric nitrogen into ammonia, a form available to plants. They have also been reported to promote plant growth, particularly root growth, which can allow the plant to take up more nutrients and reduce losses through leaching. Because of the ability of these microbes to fix nitrogen and improve the uptake of nutrients through increased root growth it has been suggested that applications of TwinN® and BB5® can maintain productivity with reduced inputs of nitrogen fertilisers.

The effect of soil and foliar applications of TwinN® and soil applications of BB5® on tree growth, fruit quality and yield in 'Hass' avocado was investigated at three sites.**3.2 Materials and Methods**

3.2.1 Experiment 1: Central Queensland

3.2.1.1 Trees and treatments

In the 2010/11 cropping season soil and foliar applications of TwinN® were applied to 3½ year old 'Hass' trees grown in a commercial orchard near Bundaberg in Central Queensland (latitude 25°S). An untreated control was included for comparison.

The microbes were rehydrated in 50 ml of rainwater prior to treatment in a container with a food source. Microbes were rehydrated the night before and stored in the refrigerator for use the next day. 50 ml of the rehydrated microbe solution is recommended to treat one hectare or around 200 trees. To treat 20 trees 5 ml of the rehydrated microbe solution was mixed in 200 litres of rainwater. Soil treatments were applied as a drench at a rate of 10 litres per tree to a $2m^2$ area around the tree trunk. The microbe solution was applied to moist soil and was followed by an irrigation to ensure the microbes reach the root zone. Foliar treatments were applied using a motorised spray unit to moist leaves in the morning to prevent drying out of the microbes. To treat 20 trees 10 ml of the rehydrated microbe solution was mixed in 200 litres of rainwater. Trees were sprayed to the point of run-off using five litres per tree (1000 L/ha). Soil and foliar rates applied were in accordance to those recommended by the supplier.

The experiment consisted of three treatments with each treatment applied to a two rows of 20 trees. Treatments in 2010/11 cropping season included:

1. Untreated (Control)
2. Soil applied TwinN®
3. Foliar applied TwinN®

Treatments were applied in August 2010 (floral buds were at the cauliflower stage of development), in November 2010 (maturity of the spring growth flush) and in April 2011 (maturity of the summer growth flush and prior to floral bud development).

In the 2011/12 cropping season the soil applied TwinN® treatment was repeated. However, the foliar applied TwinN® treatment was replaced with another source of freeze dried microbes (BB5®). BB5® consists of TwinN® plus additional microbes. TwinN® microbes were prepared as previously described. The additional microbes were rehydrated in 220 ml of rainwater. To treat 20 trees 5 ml of the TwinN® solution and 22 ml of the additional microbe solution was mixed in 200 litres of rainwater and applied to the soil as previously described. An untreated control was included for comparison.

The experiment consisted of three treatments with each treatment applied to two rows of 20 trees. Treatments in 2011/12 cropping season included:

1. Untreated (Control)
2. Soil applied TwinN®
3. Soil applied BB5®

Treatments were applied in October 2011 (early fruit set) and in March 2012 (maturity of the summer growth flush).

The trial plot consisted of six rows of trees split into two blocks with three rows each. Three treatments were randomly allocated to the rows within each block in a randomised block design with row as the experimental unit. Yield variables were recorded on 10 trees within each row. Dry matter was recorded for five fruit and severity and incidence variables were recorded for 20 fruit within each of the five trees. Analyses are performed using an ANOVA with treatment as the treatment effect and Block, Row within Block, Tree within Row and Block and Fruit within Tree, Row and Block as potential blocking effects.

3.2.1.2 Shoot growth and yield

The effect of microbial treatment on shoot growth was assessed in 10 fruiting and 10 non-fruiting shoots in 20 trees for each treatment. In both years trees were harvested by the end of June and the number and weight of fruit from each tree was recorded. Average fruit weight was calculated from the data. Cumulative yields were also calculated over the two years.

3.2.1.3 Fruit quality

At harvest 20 fruit of uniform size were sampled from 10 trees for each treatment and ripened at 20°C. A further five fruit per tree were sampled at the time of harvest to determine fruit maturity. Percentage dry matter was determined as described earlier (section 1.2.1.2).

At the eating soft stage fruit were visually rated for the severity of rots and internal disorders as described earlier (section 1.2.1.2). The effect of treatment on the severity (% of flesh affected) and incidence (% of fruit affected) of fruit rots and disorders were determined.

3.2.1.4 Root growth and tree health

In the 2010/11 cropping season the effect of microbial treatment on root growth was assessed in six trees for each treatment using 'root windows' (A Whiley, personal communication). Windows were installed by scraping back any mulch, leaf litter and about 1 cm of soil and placing a clear perspex sheet (500 x 500 x 2 mm) on the soil at one site 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. Root growth was assessed three months after treatment on 15 November 2010, 24 February 2011 and 27 July 2011. The length of the visible non-suberised roots (usually white to light brown) were assessed by removing the mulch and black foam, and tracing the outline of roots visible at the soil-perspex interface onto plastic sheets with a black permanent marker. The root tracings were measured and the total length (metres) of non-suberised roots for each perspex sheet was calculated.

The canopy of each tree was visually rated for tree health according to the Ciba-Geigy scale (Darvas *et al.*, 1984; Bezuidenhout *et al.*, 1987) where 0 = healthy and 10 = dead. Canopy health was assessed at the commencement of the trial in August 2010 and at the completion of the trial after harvest in July 2012.

3.2.2 Experiment 2: Southern Queensland

3.2.2.1 Trees and treatments

In the 2010/11 cropping season soil and foliar applications of TwinN® were applied to 11 year old 'Hass' trees grown in a commercial organic orchard in Southern Queensland. An untreated control was included for comparison.

The microbes were rehydrated as described earlier. Soil applications were made through the grower's irrigation system while foliar treatments were by spray unit delivering 10 litres per tree.

The experiment consisted of three treatments with each treatment applied to two rows of 15 trees. Treatments in 2010/11 cropping season included:

1. Untreated (Control)
2. Soil applied TwinN®
3. Foliar applied TwinN®

Treatments were applied in April 2010 at maturity of the summer growth flush and prior to bud development; in October 2010 at early fruit set and again in April 2011 at the maturity of the summer growth flush.

The trial plot consisted of six rows of trees split into two blocks with three rows each. Three treatments were randomly allocated to the rows within each block in a randomised block design with row as the experimental unit. Yield variables were recorded on three trees within each row. Dry matter was recorded for five fruit and severity and incidence variables were recorded for 20 fruit within each of the three trees. Analyses are performed using an ANOVA with treatment as the treatment effect and Block, Row within Block, Tree within Row and Block and Fruit within Tree, Row and Block as potential blocking effects.

3.2.2.2 Fruit yield and quality

The effect of microbial treatment on fruit yield and quality was assessed in 10 trees for each treatment. Trees were harvest in July 2011 and the number and weight of fruit in each tree was recorded. Average fruit weight was calculated from the data. A further five fruit per tree were sampled at the time of harvest to determine fruit maturity. Percentage dry matter was determined as described earlier (section 1.2.1.2).

At the eating soft stage fruit were visually rated for the severity of rots and internal disorders as described earlier (section 1.2.1.2). The effect of treatment on the severity (% of flesh affected) and incidence (% of fruit affected) of fruit rots and disorders were determined.

3.2.2.3 Root growth

The effect of microbial treatment on root growth was assessed in six trees for each treatment using 'root windows'. Windows were installed as described earlier in July 2010. Root growth was assessed three months after second treatment on 31 January 2011. The length of the visible non-suberised roots (usually white to light brown) were assessed by removing the mulch and black foam, and tracing the outline of roots visible at the soil-perspex interface onto plastic sheets with a black permanent marker. The root tracings were measured and the total length (metres) of non-suberised roots for each perspex sheet was calculated.

3.2.3 Experiment 3: Northern New South Wales

3.2.3.1 Trees and treatments

In the 2011/12 cropping season soil applications of TwinN® and BB5® were applied to six year old 'Hass' trees grown in a commercial orchard near Tweed Heads in Northern New South Wales. An untreated control was included for comparison. The microbes were rehydrated as described earlier. Treatments were applied as a soil drench at a rate of 10 litres per tree under the canopy.

The experiment consisted of three treatments and seven single tree replications per treatment in a completely randomised design. Treatments in 2011/12 cropping season included:

1. Untreated (Control)
2. Soil applied TwinN®
3. Soil applied BB5®

Treatments were applied in December 2011 at maturity of the spring growth flush and again in April 2012 at the maturity of the summer growth flush and prior to floral bud development.

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

3.2.3.2 Shoot growth, flowering and yield

The effect of microbial treatment on shoot growth and flowering was assessed in 10 fruiting and 10 non-fruiting shoots in seven trees for each treatment in September 2012. Trees were harvested by the end of October 2012 and the number and weight of fruit from each tree was recorded. Average fruit weight was calculated from the data.

3.2.3.3 Tree health

The canopy of each tree was visually rated for tree health according to the Ciba-Geigy scale (Darvas *et al.*, 1984; Bezuidenhout *et al.*, 1987) where 0 = healthy and 10 = dead. Canopy health was assessed at the flowering in September 2012.

3.3 Results

3.3.1 Experiment 1: Central Queensland

3.3.1.1 Shoot growth and yield

In the 2010/11 cropping season, growth in both fruiting and non-fruiting shoots was significantly increased by soil and foliar TwinN® application (Table 1). There was no significant effect of treatment on the number of fruit, yield and average fruit weight in 2011 (Table 1).

Table 1 Effect of microbial treatments (soil and foliar TwinN®) on shoot growth, number of fruit, yield and average fruit weight in 4 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Spring and summer shoot growth was measured in December 2010 and April 2011, respectively. Shoot growth data are means of 200 fruiting and non-fruiting shoots from 20 trees per treatment. Yield data are means of 20 trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Fruiting shoot length (cm)	Non-fruiting shoot length (cm)	No. of fruit	Yield (kg/tree)	Av. fruit wt (g)
Untreated (Control)	14.2 b	40.7 b	253 a	69.8 a	277.3 a
Soil applied TwinN®	16.1 a	42.9 a	255 a	71.0 a	281.1 a
Foliar applied TwinN®	16.1 a	43.0 a	287 a	77.9 a	272.6 a

In the 2011/12 cropping season there was no significant effect of microbial treatment on shoot growth (Table 2). There was a trend for an increase in the number of fruit and yield (kg/tree) in trees receiving the soil applied TwinN® treatment with 274 fruit and 52.3 kg/tree compared with 216 and 42.6 k/tree in the untreated control (Table 2).

Table 2 Effect of microbial treatments (TwinN® & BB5®) on shoot growth, number of fruit, yield and average fruit weight in 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland. Spring and summer shoot growth was measured in December 2010 and April 2011, respectively. Shoot growth data are means of 200 fruiting and non-fruiting shoots from 20 trees per treatment. Yield data are means of 20 trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Fruiting shoot length (cm)	Non-fruiting shoot length (cm)	No. of fruit	Yield (kg/tree)	Av. fruit wt (g)
Untreated (Control)	11.7 a	31.7 a	216 a	42.6 a	200.1 a
Soil applied TwinN®	11.9 a	32.1 a	274 a	52.3 a	196.2 a
Soil applied BB5®	12.0 a	32.1 a	226 a	44.5 a	201.3 a

3.3.1.2 Fruit quality

In 2011 there was no significant effect of soil and foliar application of TwinN® on maturity at harvest (27.8 - 28.0 %DM) and skin colour when ripe (ratings of 4.8 - 4.9). However, fruit sampled from the foliar TwinN® treated trees took significantly longer to ripen with 11.9 days to reach the eating soft stage compared with 11.4 in untreated control trees (Table 3). There was a trend towards a reduction in the severity of vascular browning, stem end rots and body rots in fruit sampled from trees receiving the soil applied TwinN® treatment with 2.1, 2.5 and 2.4% of the flesh affected, respectively compared with 2.7, 3.4 and 3.6% in the untreated control trees (Table 3).

Table 3 Effect of microbial treatments (soil and foliar TwinN®) on fruit ripening (days to eating soft) and the severity of vascular browning, stem end rots and body rots. Fruit was sampled from 4 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 26 June 2011 and ripened at 20ºC. Severity values represent the percentage of flesh affected. Values are the means of 200 fruit from 10 trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Days to eating soft	Severity Vascular browning	Stem end Rots	Body Rots
Untreated (Control)	11.6 b	2.7	3.4	3.6
Soil applied TwinN®	11.4 b	2.1	2.5	2.4
Foliar applied TwinN®	11.9 a	2.4	3.1	3.2

Due to the non-normality of the severity data the effect of treatment on fruit quality was statistically analysed by comparing the incidence (% of fruit affected) of fruit rots and disorders. In 2011 there was no significant effect of soil and foliar application of TwinN® (Table 4). However, soil application of TwinN® tended to reduce the incidence of vascular browning, stem end rots and body rots with 5.5, 10.5 and 10.0% of the fruit having at least 10% of the flesh affected, respectively compared with 11.5, 15.5 and 20.0% in the untreated control trees.

There was also a trend towards a higher percentage of acceptable fruit (% of fruit with less than 10% of the flesh affected by rots and disorders) is trees receiving soil applied TwinN® with 70.5% compared with 59.0% in the untreated control trees (Table 4).

Table 4 Effect of microbial treatments (soil and foliar TwinN®) on the incidence of vascular browning, stem end rots and body rots and the percentage of acceptable fruit. Fruit was sampled from 4 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 26 June 2011 and ripened at 20 ºC. Incidence values represent the percentage of fruit with at least 10% of the flesh affected Acceptable fruit values represent the percentage of fruit with less than 10% of the flesh affected by rots and disorders. Values are the means of 200 fruit from 10 trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Incidence Vascular browning	Stem end Rots	Body Rots	Acceptable fruit
Untreated (Control)	11.5 a	15.5 a	20.0 a	59.0 a
Soil applied TwinN®	5.5 a	10.5 a	10.0 a	70.5 a
Foliar applied TwinN®	7.5 a	15.5 a	14.5 a	67.0 a

In 2012 there was a significant effect of microbial treatment on fruit maturity at harvest with 27.7 and 27.8 %DM in trees treated with TwinN® and BB5®, respectively compared with 27.2% in the untreated trees. There was no significant effect of treatment on skin colour when ripe (ratings of 4.9 - 5.0) and fruit ripening (12.2 - 12.3 days to reach eating soft). There was a trend towards a reduction in the severity of vascular browning, stem end rots and body rots in fruit sampled from trees receiving TwinN® with 2.9, 3.0 and 2.1% of the flesh affected, respectively compared with 5.0, 5.1 and 3.3% in the untreated control trees (Table 5).

Table 5 Effect of microbial treatments (TwinN® and BB5®) on fruit ripening (days to eating soft) and the severity of vascular browning, stem end rots and body rots. Fruit was sampled from 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 28 May 2012 and ripened at 20ºC. Severity values represent the percentage of flesh affected. Values are the means of 200 fruit from 10 trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Days to Eating Soft	Severity		
		Vascular browning	Stem end Rots	Body Rots
Untreated (Control)	12.2 a	5.0	5.1	3.3
Soil applied TwinN®	12.3 a	3.0	3.0	2.1
Soil applied BB5®	12.3 a	4.4	4.5	3.4

Due to the non-normality of the severity data the effect of treatment on fruit quality was statistically analysed by comparing the incidence (% of fruit affected) of fruit rots and disorders. In 2012 TwinN® significantly reduced the incidence of vascular browning, stem end rots and body rots with 15.5, 15.5 and 8.5% of the fruit having at least 10% of the flesh affected, respectively compared with 29.5, 30.5 and 17.5% in the untreated control trees (Table 6). There was also significantly more acceptable fruit (% of fruit with less than 10% of the flesh affected by rots and disorders) is trees receiving TwinN® with 62% compared with 49% in the untreated control trees (Table 6).

Table 6 Effect of microbial treatments (TwinN® and BB5®) on the incidence of vascular browning, stem end rots and body rots and the percentage of acceptable fruit. Fruit was sampled from 5 year old 'Hass' avocado trees near Bundaberg in Central Queensland on 28 June 2012 and ripened at 20 ºC. Incidence values represent the percentage of fruit with at least 10% of the flesh affected. Acceptable fruit values represent the percentage of fruit with less than 10% of the flesh affected by rots and disorders. Values are the means of 200 fruit from 10 trees per treatment. Means within columns with the same letter are not significantly different ($P <$ 0.05).

Treatment	Incidence			Acceptable fruit
	Vascular browning	Stem end Rots	Body rots	
Untreated (Control)	29.5 a	30.5 a	17.5 a	49.0 b
Soil applied TwinN®	15.5 b	15.5 b	8.5 b	62.0 a
Soil applied BB5®	24.5 a	24.5 a	19.0 a	47.0 b

3.3.1.3 Root growth and tree health

In November 2010 the mean length of non-suberised roots was significantly greater in trees receiving the soil applied TwinN® with 3.95 m compared with 0.98 m in the untreated trees (Table 7). While in February 2011 the mean length of roots tended to be greatest in the foliar applied TwinN® treatment. There was no difference in the amount of root growth in July 2011 three months after the third application.

There was no significant effect of microbial treatments on tree health. At the commencement of the trial in August 2010 average tree health ratings ranged from 1.6 to 1.8 and at the completion of the trial after harvest in July 2012 tree health ratings ranged from 2.4 to 2.8 (on the Ciba-Geigy scale where 0 = healthy and 10 = dead).

Table 7 Effect of microbial treatments (soil and foliar TwinN®) on root growth in 'Hass' avocado trees near Bundaberg in Central Queensland. Root growth was assessed three months after treatment in November 2010, February 2011 and July 2011. Values are the means of six trees. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Root length (m)		
	15 Nov 2010	24 Feb 2011	27 Jul 2011
Untreated (Control)	0.98 b	4.72 a	7.92 a
Soil applied TwinN®	3.95 a	6.84 a	8.54 a
Foliar applied TwinN®	2.34 ab	7.65 a	9.61 a

3.3.2 Experiment 2: Southern Queensland

3.3.2.1 Fruit yield and quality

In the 2010/11 cropping season there was a trend towards an increase in the number of fruit and yield in the soil applied TwinN® treatment with 1007 fruit and 256.5 kg/tree compared with 810 fruit and 205.8 kg/tree in the untreated trees (Table 8). Fruit size was significantly smaller in trees treated with foliar TwinN® (Table 8).

Table 8 Effect of microbial treatments (soil and foliar TwinN®) on the number of fruit, yield and average fruit weight in 12 year old 'Hass' avocado trees in Southern Queensland. Trees were harvested in July 2011. Data are means of six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Untreated (Control)	810 a	205.8 a	254.3 a
Soil applied TwinN®	1007 a	256.5 a	255.5 a
Foliar applied TwinN®	713 a	176.1 a	247.6 b

There was a significant effect of microbial treatment on fruit maturity at harvest with 27.5 and 27.7 %DM in fruit sampled from trees treated with soil and foliar TwinN® compared with 26.7% in the untreated control trees. Fruit also tended to take longer to ripen with 12.0 and 12.1 days to reach the eating soft stage in the foliar and soil TwinN® treated trees compared with 11.6 in untreated control trees (Table 9).

The effect of microbial treatment on the severity of fruit rots and disorders is presented in Table 9. Although there was no significant effect of microbial treatment, the severity of vascular browning, stem end rots and body rots tended to be least in fruit sampled from soil TwinN® treated trees with 1.4, 1.3 and 1.0%, respectively compared with 2.2, 2.0 and 2.3% in the untreated control trees (Table 9).

Table 9 Effect of microbial treatments (soil and foliar TwinN®) on fruit ripening (days to eating soft) and the severity of vascular browning, stem end rots and body rots. Fruit was sampled from 12 year old 'Hass' avocado trees in Southern Queensland on 7 July 2011 and ripened at 20ºC. Severity values represent the percentage of flesh affected. Values are the means of 120 fruit from six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Days to eating soft	Severity		
		Vascular browning	Stem end Rots	Body Rots
Untreated (Control)	11.6 a	2.2	2.0	2.3
Soil applied TwinN®	12.1 a	1.4	1.3	1.0
Foliar applied TwinN®	12.0 a	1.6	1.3	1.5

Due to the non-normality of the severity data the effect of treatment on fruit quality was statistically analysed by comparing the incidence (% of fruit affected) of fruit rots and disorders. Although there was no significant effect of microbial treatment, both soil and foliar applied TwinN® tended to reduce the incidence of vascular browning (4.2 & 5.0%), stem end rots (5.8 & 5.0%) and body rots (both 0.5%) compared with 8.3, 9.2, and 5.8% in the untreated control trees (Table 10). There was a significantly more acceptable fruit in trees receiving soil and foliar applications TwinN® with 85.0 and 85.8% compared with 71.7% in the untreated control trees (Table 10).

Table 10 Effect of microbial treatments (soil and foliar TwinN®) on the incidence of vascular browning, stem end rots and body rots and the percentage of acceptable fruit. Fruit was sampled from 12 year old 'Hass' avocado trees in Southern Queensland on 7 July 2011 and ripened at 20 ºC. Incidence values represent the percentage of fruit with at least 10% of the flesh affected. Acceptable fruit values represent the percentage of fruit with less than 10% of the flesh affected by rots and disorders. Values are the means of 120 fruit from six trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Incidence			Acceptable Fruit
	Vascular browning	Stem end Rots	Body Rots	
Untreated (Control)	8.3 a	9.2 a	5.8 a	71.7 b
Soil applied TwinN®	4.2 a	5.8 a	0.8 a	85.0 a
Foliar applied TwinN®	5.0 a	5.0 a	0.8 a	85.8 a

3.3.2.2 Root growth

Root growth was significantly increased by microbial treatment. In January 2011 (three months after the second microbial treatment) the mean length of non-suberised roots was significantly greater in trees receiving TwinN® with 4.0 and 4.2m in the foliar and soil applied treatments compared with 2.5m in the grower control trees.

3.3.3 Experiment 3: Northern New South Wales

3.3.3.1 Shoot growth, flowering and yield

Shoot growth was significantly increased in trees receiving soil applied BB5® with a mean length of 11.9 and 26.6 cm in fruiting and non-fruiting shoots compared with 10.3 and 23.5 cm in the untreated trees (Table 11). There was no significant effect of microbe treatment on the percentage of shoots flowering. However, percentage flowering was greatest in trees receiving BB5® with 85.7% of the fruiting shoots and 94.3% of the non-fruiting shoots flowering the next season compared with 71.4 and 84.3% in untreated control trees (Table 11).

Table 11 Effect of microbial treatments (TwinN® & BB5®) on shoot growth and flowering in six year old 'Hass' avocado trees near Tweed Heads in Northern New South Wales. Shoot assessments were made in September 2012. Data are means of 70 fruiting and non-fruiting shoots from seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Fruiting shoot		Non-fruiting shoot	
	Length (cm)	Flowering (%)	Length (cm)	Flowering (%)
Untreated (Control)	10.3 b	71.4 a	23.6 c	84.3 a
Soil applied TwinN®	11.4 ab	81.4 a	25.1 b	91.4 a
Soil applied BB5®	11.9 a	85.7 a	27.3 a	94.3 a

There tended to be more fruit (241 and 225) and a greater yield (64.2 and 64.8 kg/tree) in trees treated with TwinN® and BB5®, respectively compared with 124 fruit and 33.2 kg/tree in the untreated control trees (Table 12). Fruit size tended to be larger in the BB5® treated trees with an average fruit weight of 286.5 g compared with 258.0g in the untreated control trees.

Table 12 Effect of microbial treatments (TwinN® & BB5®) on the number of fruit, yield and average fruit weight in six year old 'Hass' avocado trees near Tweed Heads in Northern New South Wales. Trees were harvested by October 2012. Data are means of seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg/tree)	Av. fruit wt (g)
Untreated (Control)	124 a	33.2 a	258.0 a
Soil applied TwinN®	241 a	64.2 a	269.7 a
Soil applied BB5®	225 a	64.8 a	286.5 a

3.3.3.2 Tree health

A significant improvement in tree health was observed in trees receiving microbial treatments at this site (Table 13). Trees treated with BB5® and TwinN® had a health rating of 3.0 and 3.2 compared with 4.4 in the untreated control trees (on the Ciba-Geigy scale where 0 = healthy and 10 = dead).

Table 13 Effect of microbial treatments (TwinN® and BB5®) on tree health in six year old 'Hass' avocado trees near Tweed Heads in Northern New South Wales. Tree health was rated in September 2012 using the Ciba-Geigy scale where 0 = healthy and 10 = dead. Tree health values are means from seven trees per treatment. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	Tree health (0 – 10)
Untreated (Control)	4.4 a
Soil applied TwinN®	3.2 b
Soil applied BB5®	3.0 b

3.4 Discussion

The results of these trials indicate the application of TwinN® and BB5® (formulations of root-colonising nitrogen fixing bacteria) can increase feeder root activity in 'Hass' avocado. This increase in root growth and possible nutrient uptake may be responsible for improvements in shoot growth, tree health and fruit quality observed at some of the experimental sites.

Bower (2011) reported that in trials on citrus in South Africa and Australia a reduction of 25% (~35kg N/ha) in annual nitrogen levels was possible in combination with TwinN® without loss of yield or reduced leaf nitrogen levels. In addition to supplying nitrogen via fixation of atmospheric nitrogen, the use of microbial bio-fertilisers has been shown to increase root growth activity thereby increasing the potential uptake of nitrogen and other nutrients from the soil.

The application of TwinN® has also been reported to suppress soil pathogens (Bower, 2011). Results from the USDA show that application of Roundup herbicide to soya beans increased root infection by *Fusarium* however, when TwinN® was added a reduction in root infection back to the levels prior to Roundup application was observed.

In the current trials microbial application was in addition to the grower's regular nutritional program and further work is required to determine if any reduction in nitrogen fertiliser application can be made when using these products before grower recommendations can be made. Further testing is also required to identify if application of these microbes can assist in reducing *Phytophthora cinnamomi* populations in avocado soils.

4. Effect of branch scoring on fruit size and yield

4.1 Introduction

Cincturing, girdling, ringing and scoring refer to the complete severance of the phloem on a limb or trunk of a tree either by a narrow incision or removal of a strip of bark and have been widely used to promote flowering and fruiting in tree crops (Noel, 1970).

The main effect of cincturing is the interruption of the phloem movement of photoassimilates and phytohormones from the cinctured branch to other parts of the tree (Noel 1970; Tomer, 1977; Davie *et al*., 1995). When successfully carried out cincturing does not interrupt the movement of water and solutes from roots to leaves via the xylem and the wound will produce callus tissue and eventually heal, thereby restoring the normal function of the branch (Noel, 1970)

Cincturing has been reported to increase flowering and yield in avocados (Lahav *et al*., 1971*a*; Ticho, 1971; Trochoulias and O'Neill, 1976; Tomer, 1977; Köhne, 1992). Lahav *et al*. (1971*a*) and Trochoulias and O'Neill (1976) reported an increase in yield in avocado trees that were cinctured for three consecutive years. However, conventional cincturing involving the removal of a band of bark was too severe resulting in tree decline with reduced yield in the second year after cincturing (Hackney *et al*. 1995).

The effect of branch scoring in autumn on fruit size and yield was investigated in 'Hass' trees in Central New South Wales and South-West Western Australia and 'Shepard' trees in Central Queensland. The effect of scoring on fruit size and yield in vigorous regrowth in stumped 'Hass' trees were also investigated at the Central Queensland site. Scoring involved cutting a groove no more than 3mm wide around the branch to sever the phloem using a knife or pruning saw.

4.2 Materials and Methods

4.2.1 Experimental sites and trees

4.2.1.1 Central New South Wales

Trials were conducted on two commercial orchards near Comboyne in Central New South Wales (latitude 31°S).

Site 1: A single branch was scored in four year old 'Hass' trees in May 2008. The procedure was repeated in May 2009 when two to four branches were scored. The effect of branch scoring on yield was assessed in 15 trees in October 2009 and 2010. Yield assessments were made on a scored branch and a similar non-scored branch within the tree. Total fruit yield in each tree was also collected.

Site 2: A single branch was scored in four year old 'Hass' trees in May 2010. The effect of branch scoring on the number of fruit was assessed in 15 trees in October 2011. Fruit yield assessments were made on the scored branch and a similar non-scored branch within the tree. The total number of fruit in each tree was also counted.

4.2.1.2 South-West Western Australia

Trials were conducted on four commercial orchards near Pemberton and Manjimup in South-West Western Australia (latitude 34°S).

Site 1: In April 2007 a single branch was scored in three year old 'Hass' trees in an orchard near Pemberton. The procedure was repeated in April 2008 when another branch was scored. The effect of branch scoring on fruit yield was assessed in 15 trees in October 2008 and December 2009. Fruit yield assessments were made on the scored branch and a similar non-scored branch within the tree. Total fruit yield in each tree was also collected in the 2009 harvest.

Site 2: In April 2009 a single branch was scored in 2½ year old 'Hass' trees in an orchard near Pemberton. The procedure was repeated in April 2010 when another branch was scored. The effect of branch scoring on the number of fruit, fruit size and yield was assessed in 10 trees in December 2010. Fruit yield assessments were made on the scored branch and a similar non-scored branch within the tree. Total fruit yield in each tree was also collected.

Site 3: A single branch was scored in 3 year old 'Hass' trees in an orchard near Manjimup in April 2010. The effect of branch scoring on the number of fruit was assessed in 19 trees in December 2011. Fruit yield assessments were made on the scored branch and a similar non-scored branch within the tree. The total number of fruit in each tree was also counted.

Site 4: A single branch was scored in 3 year old 'Hass' trees in an orchard near Pemberton in April 2010. The effect of branch scoring on the number of fruit, fruit size and yield was assessed in 10 trees in December 2011. Fruit yield assessments were made on the scored branch and a similar non-scored branch within the tree. Total fruit yield in each tree was also collected. Trees with no scored branches were included for comparison.

4.2.1.3 Central Queensland

Two trials were conducted in a commercial orchard near Bundaberg in Central Queensland (latitude 25ºS).

Trial 1: A single branch was scored in five year old 'Shepard' trees in April 2009. The effect of branch scoring on fruit yield was assessed in seven trees in March 2010 Fruit yield assessments were made on the scored branch and a similar non-scored branch within the tree. Total fruit yield in each tree was also collected.

Trial 2: 'Hass' trees were cut back to a stump approximately one metre above the graft union in June 2009. By May 2010 there was significant amount of regrowth with 6 to 8 branches produced from each stump. A single branch was scored in May 2010. The effect of branch scoring on yield was assessed in 10 trees in May 2011. Yield assessments were made on the scored branch and a similar non-scored branch within the tree. Total fruit yield in each tree was also collected. Trees with no scored branches were included for comparison.

4.2.2 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.

4.3 Results

4.3.1 Central New South Wales

Site 1: At this site scoring in May significantly increased the number of fruit and yield in branches the following year (Table 1). However, in the second year after scoring there is less fruit on that branch. Branches scored in May 2008 averaged 56 fruit in 2009 compared with 23 fruit in the 2010 harvest. Average fruit weight on the scored branch was significantly reduced in 2009.

Table 1 Effect of branch scoring on the number of fruit, yield and average fruit weight in 'Hass' avocado trees grown in Central NSW. Trees were 5½ and 6½ year old at the time of harvest in October 2009 and 2010. Values are means of 15 trees. In each year of harvest means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg)	Av. fruit wt (g)
2009 Harvest			
Non-scored branch	4 b	1.1 b	286.8 a
Scored branch (2008)	56 a	15.4 a	277.0 a
Total Tree	136	39.2	287.5
2010 Harvest			
Non-scored branch	46 b	12.9 b	280.1 b
Scored branch (2008)	23 c	6.7 c	299.6 a
Scored branch (2009)	73 a	19.9 a	274.6 b
Total Tree	329	91.9	279.6

Site 2: At this site scoring tended to increase yield with the scored branch averaging 54 fruit compared with 38 fruit on a similar non-scored branch. Trees averaged at total of 207 fruit.

4.3.2 South-West Western Australia

Site 1: In both years of the trial scoring in the autumn significantly increased in the number of fruit and yield in branches the following year (Table 2). However, in the second year after scoring there was less fruit on that branch. Branches scored in April 2007 averaged 77 fruit in 2008 compared with 14 fruit in the 2009 harvest. Average fruit weight on the scored branch was significantly reduced particularly in the second year of the trial, with 211.3 g compared with 231.8 g in the non-scored branch.

Site 2: At this site scoring significantly increased yield on the branch the following year. Branches scored in April 2009 averaged 40 fruit at harvest in December 2010 compared with 11 fruit on a similar non-scored branch (Table 3). Scoring in April 2010 increased fruit size in those branches harvested in December with a mean fruit size of 260.7g compared with 233.5g in non-scored branches with a similar yield.

Site 3: At this site scoring significantly increased yield with the scored branch averaging 48 fruit compared with 16 fruit on a similar non-scored branch. Trees averaged a total of 84 fruit.

Table 2 Effect of branch scoring on the number of fruit, yield and average fruit weight in 'Hass' avocado trees grown in South-West Western Australia. Trees were approximately 4½ and 5½ year old at the time of harvest in October 2008 and December 2009. Values are means of 15 trees. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg)	Av. fruit wt (g)
2008 Harvest			
Non-scored branch	30 b	7.9 b	275.2 a
Scored branch	77 a	20.3 a	264.9 b
2009 Harvest			
Non-scored branch	31 b	7.1 b	231.8 b
Scored branch (April 2007)	14 b	3.1 b	248.9 a
Scored branch (April 2008)	82 a	16.6 a	211.3 c
Total Tree	185	39.9	220.0

Table 3 Effect of branch scoring on the number of fruit, yield and average fruit weight in 'Hass' avocado trees grown in South-West Western Australia. Trees were 4 year old at the time of harvest in December 2010. Values are means of 10 trees. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg)	Av. fruit wt (g)
Non-scored branch	11 b	2.5 b	233.5 b
Scored branch (2009)	40 a	9.0 a	228.1 b
Scored branch (2010)	13 b	3.3 b	260.7 a
Total Tree	82	19.1	234.8

Site 4: There was no significant effect of branch scoring on yield at this site (Table 4). However, scoring tended to reduce fruit size with a mean fruit size of 279.8g compared with 295.8g in non-scored branches. There was also a trend for more fruit on trees with a scored branch with a mean of 138 fruit compared with 97 fruit in trees with no scored branches.

Table 4 Effect of branch scoring on the number of fruit, yield and average fruit weight in 'Hass' avocado trees grown in South-West Western Australia. Trees were 4½ year old at the time of harvest in December 2011. Values are means of 10 trees. Means within columns with the same letter are not significantly different ($P < 0.05$).

	No. of Fruit	Yield (kg)	Av. fruit wt (g)
Non-scored tree			
Single branch	14 a	4.2 a	296.4 a
Total Tree	97	28.0	289.9
Scored tree			
Non-scored branch	17 a	4.9 a	295.8 a
Scored branch	18 a	4.8 a	279.8 a
Total Tree	138	41.2	298.0

4.3.3 Central Queensland

Trial 1: Scoring significantly increased the number of fruit and yield on that branch compared with a similar non-scored branch on the same tree in 'Shepard' avocado at this site (Table 5). However scoring significantly reduced fruit size with an average fruit weight of 243.8g compared with 260.9g in the non-scored branch on the same tree.

Table 5 Effect of branch scoring on the number of fruit, yield and average fruit weight in 'Shepard' avocado trees grown in Central Queensland. Trees were 6 years old at the time of harvest in March 2010. Values are means of seven trees. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg)	Av. fruit wt (g)
Non-scored branch	36.6 b	9.5 b	260.9 a
Scored branch	102.4 a	24.6 a	243.8 b
Total Tree	250.7	63.2	252.5

Trial 2: Scoring regrowth on stumped trees increased the number of fruit and yield on that branch with a mean of 4 fruit and 1.2 kg compared with 19 fruit and 5.5 kg on a similar non-scored branch on the same tree (Table 6). There was also an increase in the total number of fruit and yield (kg/tree) in the trees having a single scored branch compared with the non-scored control trees. There was no effect of scoring on average fruit weight.

Table 6 Effect of branch scoring on the number of fruit, yield and average fruit weight in stumped 'Hass' avocado trees in Central Queensland. Trees were stumped in June 2009. A single branch was scored in May 2010 and trees were harvested in May 2011. Values are means of ten trees. Means within columns with the same letter are not significantly different ($P < 0.05$).

Treatment	No. of Fruit	Yield (kg)	Av. fruit wt (g)
<u>Control (not scored)</u>			
Non-scored branch	3 b	0.9 b	300.7 a
Total Tree	18 x	5.1 x	291.5 x
<u>Scored tree</u>			
Non-scored branch	4 b	1.2 b	294.1 a
Scored branch	19 a	5.5 a	287.4 a
Total Tree	45 y	13.0 y	289.3 x

4.4 Discussion

Branch scoring in autumn (April-May) may be a valuable tool to induce cropping in vigorous avocado trees or to control vigour and promote fruiting in regrowth on stumped trees. A significant increase in the number of fruit and yield was observed on the scored branch at six of the eight experimental sites. However due to the increase in fruit numbers mean fruit size was often reduced in the scored branch.

Several researchers have reported increased yield in avocado following cincturing (Lahav *et al*., 1971*a*; Ticho, 1971; Trochoulias and O'Neill, 1976; Tomer, 1977; Köhne, 1992; Hackney *et al*., 1995; Francis; 1996). The increase in production following cincturing was observed for three consecutive years (Lahav *et al*., 1971b; Trochoulias and O'Neill, 1976). Although cincturing 'Hass' trees in autumn, winter and spring all significantly increased yield the best result was observed when cinctures were performed in spring in South Africa (Hackney *et al.*, 1995) and in winter in California (Francis, 1996). In the current study the effect of branch scoring in autumn on cropping was only investigated for one-two years at each site.

A reduction in mean fruit size has been reported in cinctured trees (Lahav *et al*., 1971*b*; Trochoulias and O'Neill, 1976; Köhne, 1992), the later reporting that the reduction in mean fruit size was more than compensated by the 30% increase in production. Lahav *et al*. 1971b found that cincturing decreased mean fruit size which had a marketing advantage for large fruited cultivars such as 'Ettinger' and 'Fuerte' however cincturing led to over-production in 'Hass' resulting in an increase in the number of undersized fruit and was considered to be not suitable for this cultivar. The timing of the cincture can influence the effect on fruit size. Davie *et al*. (1995) reported a 35% increase in mean fruit size in 'Hass' when cincturing and scoring was applied in early summer (December) after good fruit set was established on those branches.

In 'Hass' production of small fruit with low marketability can be an issue (Köhne, 1991; Cutting, 1993; Cowan, 1997) particularly in warmer subtropical climates and cincturing in these environments may exacerbate the problem. In the current study branch scoring was conducted mainly on 'Hass' in the cooler temperate climate of the hinterland regions of Central New South Wales and the Mediterranean climate of South-West Western Australia where small fruit size is less of an issue. The increased benefit of higher yields observed at these sites outweighed any potential decrease in market acceptability of the smaller fruit.

The potential of trunk or whole tree cincturing to increase yield has been investigated as a strategy to maximise orchard production in the year prior to removing trees from crowded orchards (Toerien and Basson, 1979; Köhne, 1992). Branch scoring could also be implemented as part of a selective limb removal canopy management strategy. After the fruit is harvested the scored branch it is removed. In the current study the scored branch was not removed after harvest however yield in the second year on this branch was less than that observed on a non-scored branch.

Branch scoring may also be a useful strategy to encourage earlier cropping in regrowth on stumped or stag-horned trees. At the Central Queensland site scoring a single branch not only increased yield on that branch but also increased yield in the trees having a single scored branch compared with the non-scored control trees.

Although cincturing has been successful in increasing fruit yield particularly in the first 1-2 years after treatment in healthy trees results are generally not sustainable in the longer term and can result in a decline in tree health. Cincturing reduces the supply of carbohydrates to the roots thereby effecting growth. A reduction in the mineral content of leaves was also observed in cinctured branches resulting in leaf yellowing (Lahav *et al*., 1971*b*; Tomer, 1977).

Conventional cincturing involving the removal of a band of bark from around the trunk was reported to be too severe resulting in tree decline with reduced yield in the second year after cincturing (Hackney *et al*., 1995).

In the current study only a single branch was scored in any one year to minimise any potential negative impact on tree health. Scoring involved cutting a groove around the branch no more than 3mm wide using knife or pruning saw.

Branch scoring is still experimental and may not necessarily work under all growing conditions. It is important to note that these trials were conducted on vigorous, healthy trees. In some situations yellowing of leaves and leaf drop may occur which can expose fruit and branches to sunburn. Also due to the increase crop load on the scored branch mean fruit size can be reduced.

Technology Transfer

Field days

An update on the progress of the project was presented to growers at field days held in June 2010 in Hampton, Southern Queensland and in August 2011 in Mildura, Victoria.

Conference presentation and 'Talking Avocados' papers

World Avocado Congress
A paper titled "Evaluation of sustainable orchard management practices across Australia" was presented at the VII World Avocado Congress 2011 Cairns, Australia. 5 - 9 September 2011.

Winter 2009: Evaluation of sustainable orchard management practices. *Talking Avocados* 20(2), 26-27.

Autumn 2010: Evaluation of sustainable orchard management practices. *Talking Avocados* 21(1), 18-21.

Winter 2010: Update of the evaluation of sustainable orchard management practices. *Talking Avocados* 21(2), 42-43.

Summer 2010: Evaluation of sustainable orchard management practices. *Talking Avocados* 21(4), 30-31.

Autumn 2011: Update on sustainable orchard management practices. *Talking Avocados* 22(1), 41-43.

Winter 2011: Update on sustainable orchard management practices. *Talking Avocados* 22(2), 27-28.

Spring 2011: Update on sustainable orchard management practices. *Talking Avocados* 22(3), 33-35.

Autumn 2012: Update on sustainable orchard management practices. *Talking Avocados* 23(1), 32-33.

Winter 2012: Update on sustainable orchard management practices. *Talking Avocados* 23(2), 40-41.

Recommendations

The results from this research indicate that mulching trees with avocado woodchip and cane-tops is recommended. Growers should ensure the avocado material sourced is free of diseases such as *Verticillium wilt* before applying. The effect of mulching on water and nutritional requirements were not investigated in the current study and need to be monitored by growers when using any mulching product.

No clear recommendations at this stage can be made on the use of pyroligenous acid (PandA®). Applications of PandA® alone had no significant effect on tree growth, yield and fruit quality. However foliar applications of PandA® at 4ml/L in combination with the copper fungicide (in the same tank mix) improved fruit quality with a reduction in the incidence of fruit rots and disorders. Further work may be required to identify if this observation has any commercial benefit. Research is also required to test the effectiveness of PandA® application as a possible soil drench on *Phytophthora* root rot and other soil borne diseases that affect avocado.

The application of TwinN® and BB5® (formulations of root-colonising nitrogen fixing bacteria) can increase feeder root activity and may be responsible for improvements in tree growth and fruit quality observed at some of the experimental sites. In the current trials microbial application was in addition to the grower's regular nutritional program and further work is required to determine if any reduction in nitrogen fertiliser application can be made when using these products before grower recommendations can be made. Further testing is also required to identify if application of these microbes can assist in reducing *Phytophthora cinnamomi* populations in avocado soils.

Branch scoring in autumn may be a valuable strategy to induce cropping in vigorous avocado trees or to control vigour and promote fruiting in regrowth on stumped trees. Branch scoring is still experimental and may not necessarily work under all growing conditions.

Acknowledgments

This project was funded using avocado grower R&D levies which are matched by the Australian Government through Horticulture Australia.

Thanks to all growers who provided information on their management operations and access to their orchards to conduct trials including: Ashbourne Hills; Avocado Ridge; Avonova; Battistin Orchards, P&L Blundell Family Trust; GJ & MM Burch; Coastal Avocados; Cobra Hill Orchards; Goodlife Orchards; Googa Farms; M & N Heather; KO & JA Luzny; Manna Farms; AD, RA & JA Matthews; Peirson Memorial Trust; Premium Choice Produce; D & D Roche and Son; and Tuckerflora.

Thanks to Mapleton Agri Biotec Pty Ltd for supplying the microbial products (TwinN® and BB5®); O'Grady Rural for providing the pyroligneous acid (PandA®); King Brown Technology for providing the compost; Peter Hofman, Barbara Stubbings and the postharvest team at QDAFF, Maroochy Research Station for their assistance and use of ripening facilities; and Kerri Dawson QDAFF, Ecosciences Precinct, Dutton Park for statistical analyses.

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Appendix: Details of orchard management practices used by growers across Australia

Several growers are adopting new strategies to meet these changes in consumer expectations. The objective of this work was to identify sustainable orchard management practices used by avocado growers across Australia.

Selection of orchards

In Australia commercial avocado production occurs in a wide range of environments from the wet tropics of north Queensland (latitude 17°S) to the dry Mediterranean climate of southern Australia (latitude 34°S). A total of 15 sites were selected as case studies from the major production areas across Australia, including North, Central and Southern Queensland, Northern/Central New South Wales, the Tri-State and South-West Western Australia.

Data collection

Information on variety, rootstock, tree age, planting density, row orientation and the timing of flowering, vegetative flushing, and harvesting was collected from each site. The timing, method, rate of application, and costs of a range of orchard management practices and the impact of these practices on yield (t/ha), fruit size (pack-out figures) and quality (reject %'s) was also collected from some sites.

Analysis of Orchard Management Sites

A summary of each site including orchard strategies used at these sites is presented in the table below.

Site	Orchard Management Practices
1	Conventional grower mulching with Rhodes grass hay and using fish and seaweed concentrates and molasses
2	Conventional grower mulching with Rhodes grass hay and using fish and seaweed concentrates, silica based products and humates
3	Conventional grower mulching with Rhodes grass hay and cane-tops and using guano
4	Conventional grower mulching with filter press and using fish and seaweed concentrates and molasses
5	Conventional grower mulching with filter press and composted vegetation waste, using fish and seaweed concentrates and molasses
6	Conventional grower mulching with filter press and using guano, silica based products, brewed microbes, molasses and humic acid
7	Conventional grower using mulching, poultry manure, natural mineral fertilisers and silica based products, brewed microbes, fish emulsion, molasses and humic acid

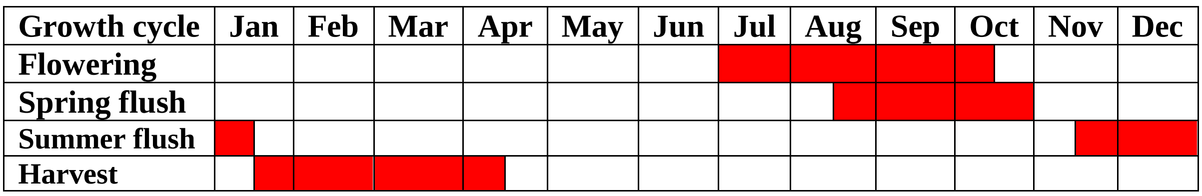
8	Organic grower mulching with pine bark and poultry manure, using brewed microbes, fish and seaweed concentrates and molasses
9	Biological grower using brewed microbes, microbial enhanced fertilisers and molasses
10	Biological grower using composted poultry manure, brewed microbes and natural mineral fertilisers
11	Biodynamic grower using compost, microbes and fish and seaweed concentrates
12	Biological grower using natural mineral fertilisers and fish and seaweed based products
13	Conventional grower using microbial enhanced fertilisers, fish and seaweed concentrates and branch scoring to maintain consistent cropping
14	Conventional grower mulching with avocado woodchip, using microbial enhanced fertilisers and fish and seaweed concentrates
15	Conventional grower mulching with inter-row slashings and avocado pruning and using silica based products

Site 1
Conventional grower using mulching, fish emulsion, seaweed concentrate and molasses

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type
Shepard	Reed	2005	10 x 6 (167 trees/ha)	E- W	500	3.01	Sandy loam
Shepard	Reed	2007	10 x 6 (167 trees/ha)	E- W	450	2.71	Sandy loam

Growth cycle:
The annual growth cycle for 'Shepard' avocado grown at this North Queensland site is presented below.



Orchard Management Objectives:

- Improve soil health and structure
- Control Phytophthora
- Increase fruit size, productivity and quality
- Reduce chemical use
- Maintain tree growth through eliminating water stress

Orchard Management Operations:

- Mulching: Rhodes grass hay annually in August, machine spread (bale-buster) at a rate of one 3 foot round bale to 1½-2 trees; Cost $800-1200/ha
- Fish emulsion: Applied by fertigation monthly from May-December at 5 L/ha and in February and March at 20 L/ha.
- Fish emulsion is also added to foliar zinc and boron sprays and applied monthly from May-December.
- Seaweed formulation (Seasol®): Applied by fertigation monthly from May-December at 5 L/ha
- Molasses: Applied by fertigation in April and August at 20 L/ha
- Leaf nutrient status monitored monthly. Soil analysis twice a year in April and September.

Harvest and pack-out figures:

	Pack-out figures (No. of trays for each size category)									
Year	**16**	**18**	**20**	**22**	**23**	**25**	**28**	**2nds**	**Bulk**	**Total 5.5kg eqv.**	**Yield (t/ha)**
2009	54	984	1967	2791	699	46	871	583	391	8704	8.4
2010	197	2176	4190	3881	3362	1279	946	-	1522	18798	18.1
2011	704	2448	3572	2822	1532	513	-	-	2005	15236	14.7
2012	-	1753	3600	3399	2915	1173	-	-	1202	15025	14.4

Site 2
Conventional grower using mulching, seaweed and fish concentrates, silica based products and humates

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	2012 Yield (t/ha)
Shepard	Velvick	2008	10.5 x 6 (159 trees/ha)	N- S	440	2.8	Sandy loam	5.6

Growth cycle:
The annual growth cycle for 'Shepard' avocado grown at this North Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering							■	■	■			
Spring flush								■	■	■		
Summer flush	■											■
Harvest		■	■									

Orchard Management Objectives:
- Improving soil health and structure
- Controlling Phytophthora
- Maximising fruit set
- Increasing fruit size, productivity and quality

Orchard Management Operations:
- Mulching: Signal grass grown in the inter-row is slashed and directed under the canopy. 1n August 2012 commenced an annual mulching program using Rhodes grass hay, machine spread using a "bale-buster"
- Seaweed formulation (Sea-Change® Liquid Kelp): Three foliar sprays applied at two week intervals during flowering in August/September
- Silica based products (Potassium silicate): Applied by fertigation in May, July and September at 7 L/ha
- Humates: Applied by fertigation in May at 2 kg/ha
- Leaf and soil nutrient analysis in April

Site 3
Conventional grower mulching with Rhodes grass and cane-tops

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	2012 Yield (t/ha)
Shepard	Unknown	1992	12 x 12 (70 trees/ha)	N- S	280	4.0	Red silty loam	11.6

Growth cycle:
The annual growth cycle for 'Shepard' avocado grown at this North Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering												
Spring flush												
Summer flush												
Harvest												

Orchard Management Objectives:
- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Reducing chemical use

Orchard Management Operations:
- Mulching: Rhodes grass hay and cane-tops, machine spread (bale buster) applied in November, 4 foot round bales at 1-1½ bales/tree; Costs $20/bale + $9/bale to spread ($35/tree, $2450/ha)
- Guano: ground applied in June at 1 kg/tree; Cost $1600/tonne
- Leaf and soil nutrient analysis in April and November

Site 4
Conventional grower mulching with filter press and using fish and seaweed concentrates and molasses

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha) 2011	Yield (t/ha) 2012
Shepard	Velvick	2007	11 x 7 (130 trees/ha)	N- S	600	4.6	Red clay	0.4	7.2

Growth cycle:
The annual growth cycle for 'Shepard' avocado grown at this Central Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering							■	■	■			
Spring flush								■	■	■		
Summer flush	■											■
Harvest			■	■								

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Reducing fertiliser costs

Orchard Management Operations:

- Mulching: Filter-press at 20 t/ha applied in August, machine spread, costs $15/tonne and $100/hr to spread (total $400/ha). Signal grass in the inter-row and avocado prunings are slashed and directed under the canopy.
- Fish emulsion: Applied by fertigation in February 2012 at 12½ L/ha and May 2012 at 20 L/ha. A program involving monthly applications at 5 L/ha commenced at flowering in September 2012.
- Molasses: Applied by fertigation in September 2011 at 7½ L/ha, January 2012 at 15 L/ha and May 2012 at 5 L/ha. A program involving monthly applications at 15 L/ha commenced at flowering in September 2012.
- Seaweed formulation: A program involving monthly applications at 5 L/ha commenced at flowering in September 2012
- Leaf and soil nutrient analysis in April and November

Site 5
Conventional grower mulching with filter press and composted vegetation waste, using fish and seaweed concentrates and molasses

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha)		
								2010	2011	2012
Hass	Velvick	2007	10 x 5 (200 trees/ha)	N- S	830	4.15	Red clay	3.6	13.7	5.1

Growth cycle:
The annual growth cycle for 'Hass' avocado grown at this Central Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering								■	■			
Spring flush									■	■	■	
Summer flush	■	■										■
Harvest					■	■	■					

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Reducing fertiliser costs

Orchard Management Operations:

- Mulching: Filter-press applied in August, machine spread at 20 t/ha; Costs $15/tonne and $100/hr to spread ($400/ha). Composted vegetation waste with added microbes applied in August at 5 t/ha; Costs $120/tonne ($600/ha). Rhodes grass in the inter-row and avocado prunings are slashed and directed under the canopy.
- Fish emulsion applied by fertigation
  2009: June (20 L/ha); 2010: August (12 L/ha); 2011: No application; 2012: February (20 L/ha), March (7 L/ha). A program involving monthly applications at 15 L/ha commenced at flowering in September 2012
- Molasses applied by fertigation
  2009: February (25 L/ha), May (12½ L/ha), September (5 L/ha) & December (10 L/ha) 2010: No applications; 2011: September (7 L/ha); 2012: January (15 L/ha) A program involving monthly applications at 15 L/ha commenced at flowering in September 2012
- Seaweed formulation: A program involving monthly applications by fertigation at 5 L/ha commenced at flowering in September 2012
- Leaf and soil nutrient analysis in April and November

Site 6
Conventional grower mulching with filter press and using guano, silica based products, brewed microbes, molasses and humic acid

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	2009 Yield (t/ha)
Hass	West Indian	2005	10 x 5 (200 trees/ha)	N- S	1600	8.0	Red clay	10.0

Growth cycle:
The annual growth cycle for 'Hass' avocado grown at this Central Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering								■	■			
Spring flush									■	■	■	
Summer flush	■	■	■									
Harvest				■	■	■	■					

Orchard Management Objectives:
- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Reducing chemical use
- Increasing profitability

Orchard Management Operations:
- Mulching: Filter-press applied in August, machine spread; maintain a low canopy skirt to retain natural leaf mulch; inter-row grass and avocado prunings slashed and directed under the canopy
- Guano: Ground applied at 625kg/ha; Cost $575/ha
- Silica product (Dia-Life): Applied by fertigation in June and October; Cost: $11.25/ha
- Microbes + food source: Applied by fertigation in August; Cost: $22.50/ha
- Molasses: Monthly applications at 7½ L/ha applied by fertigation from August - May; Cost: $3.15/ha
- Humic acid: Monthly applications by fertigation from August - May; Cost: $3.15/ha
- Leaf and soil nutrient analysis in March and May

Harvest and pack-out figures:

	Pack-out Figures (No. of trays for each size category)										
Year	**16**	**18**	**20**	**22**	**23**	**25**	**28**	**28+**	**Bulk (10 kg)**	**Total 5.5 kg eqv.**	**Yield (t/ha)**
2009	11	508	1656	-	2430	3840	1380	806	2152	14 527	10.0

Site 7

Conventional grower using mulching, poultry manure, natural mineral fertilisers and silica based products, brewed microbes, fish emulsion, molasses and humic acid

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	2009 Yield (t/ha)
Hass	Velvick	2006	9 x 5 (222 trees/ha)	N- S	600	2.7	Sandy loam	8.8

Growth cycle:

The annual growth cycle for 'Shepard' avocado grown at this Central Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering												
Spring flush												
Summer flush												
Harvest												

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality

Orchard Management Operations:

- Mulching: Rhodes grass hay applied in July/August
- Poultry manure: Pellets ground applied in November at 1 t/ha
- Natural mineral fertilisers: Natramin High Phos blend ground applied in November at 740 kg/ha
- Potassium silicate: Applied at flowering by fertigation in August and September
- Compost tea: Microbes & Trichoderma, with Bio N, P, K & Calcium silicate, fish emulsion & molasses applied by fertigation every 2 months
- Calcium (Ca Life) + Humic acid: Monthly applications by fertigation from December - February
- Kelp + Boron: Foliar application at flowering in August
- Leaf and soil nutrient analysis in April

Site 8
Organic grower mulching with pine bark and poultry manure, using brewed microbes, fish and seaweed concentrates and molasses

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha)	
								2011	2012
Hass	Guatemalan	1995	8 x 8 (156 trees/ha)	N- S	440	2.8	Red clay	22.3	8.6

Growth cycle:
The annual growth cycle for ‘Hass’ avocado grown at this Southern Queensland site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering									■	■		
Spring flush										■	■	
Summer flush	■	■										
Harvest					■	■	■	■	■	■		

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Maintain organic certification

Orchard Management Operations:

- Mulching: Pine woodchip ($1000/60m^3) mixed poultry manure ($19/tonne) applied every two months at a depth of 2.5cm; avocado trees pruned after harvest and chipped.
- Compost teas (microbes): Micro-life applied weekly by fertigation at 10 L/ha once per week; Cost $1.50/litre ($15/ha)
- Fish emulsion: Applied weekly by fertigation at 20 L/ha; Cost $0.50/litre ($10/ha)
- Seaweed formulations (natra kelp): Applied weekly by fertigation at 10 L/ha; Cost $7/litre ($70/ha)
- Molasses: Applied weekly by fertigation at 20 L/ha
- Weed control conducted monthly using whipper snipper
- Leaf and soil nutrient analysis in May

Site 9
Biological grower using brewed microbes, microbial enhanced fertilisers and molasses

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type
Hass	mixed	1991 1994 2000 2000	10 x 7 (143 trees/ha) “ 10 x 5.5 (182 trees/ha)	E- W	180 245 840 375	1.3 1.7 5.9 2.1	Sand

Growth cycle:
The annual growth cycle for ‘Hass’ avocado grown at Central New South Wales site is presented below:

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering												
Spring flush												
Summer flush												
Harvest												

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Reducing chemical use

Orchard Management Operations:

- Compost tea: Microbes + food and bio-stimulants applied by fertigation monthly during flowering and early fruit set from August - November and in February and March at 400 L/ha; Cost $50/ha
- Molasses: Applied monthly (except in January) by fertigation at 40 L/ha
- Microbial products: Nutri-Life Bio-P applied monthly (except January, June & July) by fertigation at 1 L/ha
- Leaf and soil nutrient analysis in March

Harvest and pack-out figures:

	Pack-out Figures (No. of trays for each size category)										
Year	**<16**	**16**	**18**	**20**	**22**	**23**	**25**	**28**	**28+**	**Bulks into trays**	**Total 5.5 kg eqv.**	**Yield (t/ha)**
2009	-	1934	1949	1096	348	333	176	79	3	1955	7873	3.9
2010	1854	5617	4275	3225	2238	771	365	21	29	2336	20731	10.4
2011	357	2458	4899	1589	1238	751	144	-	-	1833	13269	6.6

Site 10

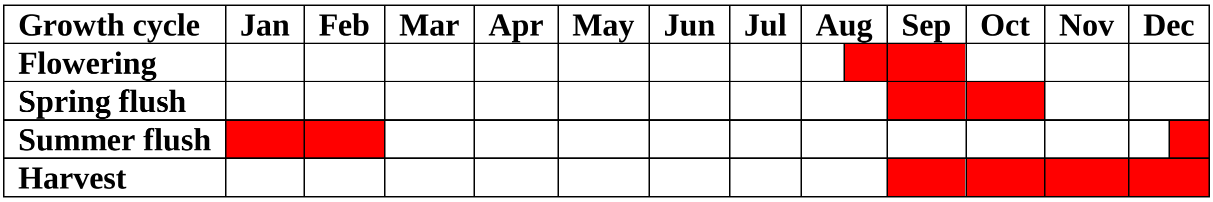
Biological grower using composted poultry manure, brewed microbes and natural mineral fertilisers

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	2009 Yield (t/ha)
Hass	Guatemalan	1999	10 x 6 (167 trees/ha)	N- S	230	1.4	Sandy loam	7.5

Growth cycle:

The annual growth cycle for ‘‘Hass’’ avocado grown at this Central New South Wales site is presented below.



Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality
- Reducing chemical use

Orchard Management Operations:

- Composted poultry manure applied in December
- Compost tea: Brewed microbes & food source applied by fertigation in September
- Natural mineral fertilisers: Ground applied in August, December and April
- Bio-fertilisers (TwinN®): Applied as a foliar spray in September
- Leaf and soil nutrient analysis in May and August

Site 11
Biodynamic grower using compost, microbes and fish and seaweed concentrates

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha)		
								2010	2011	2012
Hass	Zutano	1988	12 x 6 (138 trees/ha)	N- S	550	4.0	Red sandy loam	7.5	22.5	13.8

Growth cycle:
The annual growth cycle for ''Hass'' avocado grown at this Tri-State site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering												
Spring flush												
Summer flush												
Harvest												

Orchard Management Objectives:

- Improving soil health and structure
- Increasing fruit size, productivity and quality
- Reducing chemical use

Orchard Management Operations:

- Compost: Guano + Green manure waste applied in September and February at 1 t/ha; Cost $767.60/ha. Protein meal applied in August at 200 kg/ha; Cost $200/ha
- Microbes (Platform®): Mycorrhizal fungi and trichoderma applied by fertigation in October at 200 kg/ha; Cost $19.80/ha
- Humus: applied by fertigation in October at 10 L/ha; Cost $20.30/ha
- Liquid bio-stimulant (Vitazyme): applied by fertigation in August at 1.5 L/ha; Cost $42/ha
- Fish emulsion: applied by fertigation monthly from September - December at 10 L/ha; Cost $60/ha
- Liquid bio-stimulant (Vitazyme): applied as a foliar spray in October, December and April at 1.5 L/ha; Cost $126/ha
- Fish plus: applied as a foliar spray monthly from September - December at 10 L/ha; Cost $66.20/ha
- Kelp: applied as a foliar spray in October and monthly from December - February at 3 L/ha; Cost $37.20/ha
- Nitrogen: applied as a foliar spray monthly from September - December at 5 L/ha; Cost $102/ha
- Zinc and Manganese applied monthly from September - December; Cost $10.44 & $6.72/ha
- Total nutritional program: Cost $1467.37/ha

Site 12
Biological grower using natural mineral fertilisers and fish and seaweed based products

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha)	
								2010	2011
Hass	Guatemalan	2003	9 x 3 (370 trees/ha)	N- S	3300	8.9	Sand	29.2	6.6

Growth cycle:
The annual growth cycle for ‘‘Hass’’ avocado grown at this Tri-State site is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering									■	■		
Spring flush										■	■	
Summer flush	■	■	■									
Harvest	■	■									■	■

Orchard Management Objectives:
- Improving soil health and structure
- Increasing fruit size, productivity and quality
- Phytophthora control
- Produce robust fruit and trees to cope with heat and frost

Orchard Management Operations:
- Liquid biological nutrient and fish and seaweed concentrate: applied by fertigation at 200-300 L/ha from September - April; if soil too wet apply as a foliar spray during May - August (wet season at this site)
- Leaf nutrient analysis carried out monthly and fertiliser rates (Ammonium sulphate, Potassium sulphate, Boron, Molybdenum sulphate, Zinc, MAP etc.) modified according
  Soil nutrient analysis in July and December
  Microbial testing of the soil once a year

Site 13

Conventional grower using microbial enhanced fertilisers, fish and seaweed concentrates and branch scoring to maintain consistent cropping

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha) 2008 /09	Yield (t/ha) 2009 /10
Hass	Guatemalan	2004	9 x 5 (222 trees/ha)	E- W	900	4.05	Sandy loam	8.4	8.6

Growth cycle:

The annual growth cycle for ''Hass'' avocado grown at this site near Pemberton in South-West Western Australia is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering												
Spring flush												
Summer flush												
Harvest												

Orchard Management Objectives:

- Improving soil health and structure
- Increasing fruit size, productivity and quality
- Maintain consistent cropping

Orchard Management Operations:

- Mulching: barley straw at planting then inter-row slashings and prunings
- Eco-Vital® (a liquid formulation containing fish, kelp and plant extracts, auxins, cytokinins, gibberellins, amino acids, and rare earth minerals) applied through fertigation at 4 to 5 L/ha every 3-4 months
- Eco-Prime purple® (a formulation of mineral NPK and trace elements bonded with beneficial microbes (including beneficial bacteria and fungi – VA Mycorrhizae) broadcast application @ 20-25 g/m^2 in February, May & September
- Branch scoring: a single branch was scored in April 2007 and 2008 using a pruning saw time involved 2 minutes per tree; Costs $150/ha

Site 14

Conventional grower mulching with avocado woodchip, using microbial enhanced fertilisers and fish and seaweed concentrates

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	Yield (t/ha)	
								2008 /09	2009 /10
Hass	Guatemalan	1995	8 x 7 (180 trees/ha)	E- W	930	5.2	Sandy loam	41.3	12.3

Growth cycle:

The annual growth cycle for ''Hass'' avocado grown at this site near Pemberton in South-West Western Australia is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering										■	■	
Spring flush											■	■
Summer flush		■	■									
Harvest	■	■									■	■

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality

Orchard Management Operations:

- Mulching: major limb removal commenced in 2007, avocado limbs were chipped and applied under the trees
- Eco-Vital® (a liquid formulation containing fish, kelp and plant extracts, auxins, cytokinins, gibberellins, amino acids, and rare earth minerals) applied through fertigation at 4 to 5 L/ha every 4 months
- Eco-Prime purple® (a formulation of mineral NPK and trace elements bonded with beneficial microbes (including beneficial bacteria and fungi – VA Mycorrhizae) broadcast application at 500 g/tree in February, May & September

Site 15

Conventional grower mulching with inter-row slashings and avocado pruning and using silica based products

Block description:

Variety	Rootstock	Year planted	Spacing (row x tree) (m)	Row direction	No. of trees	Block size (ha)	Soil type	2011/12 Yield (t/ha)
Hass	Velvick	2005	8 x 5 (250 trees/ha)	N- S	465	1.85	Gravel loam	25.7

Growth cycle:

The annual growth cycle for ''Hass'' avocado grown at this site near Manjimup in South-West Western Australia is presented below.

Growth cycle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering									■	■	■	
Spring flush										■	■	
Summer flush	■	■										
Harvest	■									■	■	■

Orchard Management Objectives:

- Improving soil health and structure
- Controlling Phytophthora
- Increasing fruit size, productivity and quality

Orchard Management Operations:

- Mulching: Trees are mulch with inter-row slashings and avocado prunings
- Fertiliser: ground application fortnightly during August to March and once in April and July at 600 g/tree; Cost $155/ha

Harvest and pack-out figures:

Year	Pack-out Figures (No. of trays for each size category)										
2011/12	**16**	**18**	**20**	**23**	**25**	**28**	**Lge**	**Med**	**Sm**	**Cartons**	**Total 5.5 kg eqv.**
Premium	303	727	1401	1354	973	425	183	493	376	564	7218
Non	1	19	41	55	75	39	28	54	53	0	