Canopy management strategies for improved and sustainable productivity Part 2: completing research and supporting on-farm assessment by growers

Dr Trevor Olesen
NSW Department of Primary Industries

Project Number: MC11000

MC11000

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Canopy management strategies for improved and sustainable productivity Part 2: completing research and supporting on-farm assessment by growers

MC11000

Final report, 31 December 2013

Lisa McFadyen, David Robertson, Stephen Morris and Trevor Olesen

NSW Department of Primary Industries

Project details	
Project title	Canopy management strategies for improved and sustainable productivity Part 2: completing research and supporting on-farm assessment by growers
HAL project number	MC11000
Project leader	Dr Trevor Olesen NSW Department of Primary Industries Wollongbar Primary Industries Institute 1243 Bruxner Highway, Wollongbar NSW 2477 Telephone: 02 6626 1198 Facsimile: 02 6628 1744 Email: trevor.olesen@dpi.nsw.gov.au
Other key personnel	Dr Lisa McFadyen, David Robertson and Stephen Morris
Purpose of the report	To assess a range of canopy management options for macadamia, specifically early central leader training, root pruning, girdling and strategically timed hedging
Funding sources	This project has been funded by HAL using the macadamia industry levy and matched funds from the Australian Government, and by the NSW Government and the University of New England
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Media summary

There are pressing needs to keep macadamia trees small and productive. High amongst these is increasing light to the orchard floor. Increased light leads to more groundcover, which mitigates erosion caused by heavy rains and management practices such as sweeping and harvesting. In Project MC11000 the authors report on four techniques to control tree size.

The first technique is early tree training. The current industry recommendation is to train young trees to a central leader, but the authors found that this resulted in yield losses during the early years of production. Minimal pruning, focusing on the removal of bad crotch angles, may be a better approach.

The second technique is root pruning. The authors found it to be a useful technique in slowing the growth of trees without reducing yield, but more work is needed before it can be recommended commercially, especially in terms of suitable machinery and frequency of pruning.

The third technique is trunk girdling. It too slowed the growth of trees without reducing yield. The technique might be adopted immediately, but would benefit from further research into the width and depth of the girdle.

The fourth technique is the strategic timing of hedging. The current industry recommendation is to hedge trees in late spring or early summer, to avoid competition between early fruit development and the post-hedging flush. The recommendation was based on short term studies. In a four-year study, the authors did not detect differences in cumulative yields for tree subjected to annual pruning at different times of the year, but they did find significant yield differences between treatments in some years. The industry recommendation stands, but there are clearly complexities here that need further examination.

Technical summary

Introduction

Control of tree size will deliver several improvements to typical macadamia orchards. Soil erosion will decrease as groundcovers benefit from increased sunlight. Harvest quality and control of pathogens will improve due to increased ventilation. Machinery access will be easier and pest control more efficient. The challenge for industry has been to develop cost-effective strategies to control tree size that minimise yield reduction. The primary purpose of the current report is to examine the merits of four strategies: early tree training, root pruning, trunk girdling and strategically timed hedging.

Early tree training

The current industry recommendation for the training of young trees is to prune the trees to a central leader, mostly for structural stability, but there is little science to support this recommendation. We planted a new orchard to specifically address this question, using two varieties, ‘246’ and ‘816’, and two treatments, training to a central leader and a minimally pruned control. The varieties and treatments were replicated in five plots. Training to a central leader reduced cumulative yields over the first three years of production by 16% in ‘246’ and 23% in ‘816’. Central leader training had no obvious effects on fruit characteristics. ‘246’ produced 67% more ‘nut-in-shell’ in the first three years of production than ‘816’. ‘816’ had a larger average ‘nut-in-shell’ weight, a higher kernel recovery and a higher percentage of first grade kernel than ‘246’. The early training of the upright variety ‘816’ appeared to improve its resistance to storm damage, but no such effect was seen in the more spreading variety ‘246’. The yield penalty in training young trees to a central leader is such that industry should reconsider its recommendation.

Root pruning

Root pruning is a method for slowing the vegetative growth of horticultural trees. We conducted two experiments that compared trees that were root pruned on three occasions over four year with control trees that were not root pruned. One experiment was with variety '849', with six 3-tree plot replicates per treatment. The second experiment was with variety 'A4', with nine individual tree replicates per treatment. The trees were root pruned with a trench digger to a depth of 0.6 m. Trenches were dug parallel with the tree row at 1-1.2 m from the trunk on both sides of the tree. Root pruning reduced the shoot growth of both varieties, and the effects seemed to persist for at least two vegetative flushing cycles. No yield reduction due to root pruning was detected. The technique has promise, but more work is needed, especially into alternative methods of root pruning, and into the frequency of intervention.

Trunk girdling

Trunk girdling is commonly used in tree crops to restrict growth and increase yields. We compared trees that were trunk girdled on four occasions over five years with control trees that were not girdled, using variety '849', with eight 3-tree plot replicates per treatment. The trees were girdled using a small electrical router to remove a ring of bark, 6 mm wide, from around the whole trunk. Girdling slowed the height growth of the trees, but had no effect on the cumulative yield. The lack of a yield response may have related to the narrowness of the girdle used. The technique has immediate applications, but would benefit from further work into the effects of different girdle widths and depths on growth and production.

Strategically timed hedging

Late spring or early summer is the current industry recommendation for the side-hedging of trees. This avoids the competition between early fruit development and post-hedging flush development that occurs when trees are hedged in early spring.

The recommendation is based on short term studies. We conducted a 4-year study of trees hedged annually in June, September, December or February (the following year) relative to trees that were not hedged. The work was conducted in a 20-year-old commercial orchard on variety '344'. The analyses were based on seven 3-tree plot replicates per treatment. There was no evidence that the timing of hedging affected cumulative yields. In one season early summer hedging significantly increased yields relative to the other hedging times, but in the subsequent season the same hedging time significantly decreased yields. The cumulative yield of the control trees was much greater than that of the hedged trees. The results are not sufficient to change the current industry recommendation on hedging, but do point to complexities that warrant further investigation.

Chapter 1

Effects of early tree training on tree size and production

Introduction

NSW DPI initiated and funded the establishment of an early tree training trial at the Centre for Tropical Horticulture, Alstonville, in northern NSW. The trial was planted in March 2007. From 2009 the trial was jointly funded by NSW DPI, Horticulture Australia Limited and levy contributions from the Australian macadamia industry.

The purpose of the trial was to examine the merits of the current recommendation to train young trees to a central leader. The justification for the trial was the lack of scientific evidence to support the recommendation. The only previous research into early tree training found that training to a central leader caused a substantial yield penalty in the early years of production relative to non-pruned trees (Trochoulias 1983). However, the pruning in this study was more intensive than recommended by industry, and the relevance of the study has been questioned.

The initial results from our trial were presented in MC09003 (McFadyen *et al*. 2011) including tree dimensions from 2008 until 2011, yields in 2011, and flowering in 2010 and 2011. Consistent with Trochoulias (1983) the yields in 2011, the first year of production, were substantially lower for the trees trained to a central leader than for the minimally pruned control trees. This was true for both the spreading variety '246' and the upright variety '816'. However, the yields in the first year of production were low and there was interest in the extent to which the yield penalty would persist into subsequent years of production. For this reason the trial was monitored through two more harvest seasons. For completeness, the results of the whole trial are presented here.

Materials and methods

The two varieties used in the trial, '246' and '816', are believed to be *M. integrifolia* (Peace *et al*. 2004). The trees were grafted onto 'H2' seedling rootstocks and planted in March 2007 in north – south rows at 7 × 3.9 m spacings at the Centre for Tropical Horticulture, Alstonville (28.9°S, 153.5°E). Two treatments were applied to each variety: training to a central leader and a minimally pruned control.

All trees were pruned back to a single stem in June 2007. The remaining stem on each tree was then topped at three to four nodes above the rootstock. The control trees were not pruned again. The trained trees were pruned by largely following the guidelines described by O'Hare *et al.* (2004) with the following variations. After topping, buds in two of the three axils in the uppermost whorl on the stem were removed. The idea here was that the remaining bud would form the central leader without competition from other shoots at that node, and that shoots from the node below would form the first layer of scaffold branches. However, in August 2007, we observed that the shoot from the uppermost whorl on around 30% of the pruned trees had been lost or was stunted whereas shoots from the node below had grown more vigorously. Given this, the trees were topped back 10 to 15 mm above the second node and a central leader and scaffold branches were selected from the shoots at that node. At subsequent prunings, if no branches had formed on the central leader within approximately 60 cm of the last layer of scaffold branches, the leader was topped to promote branching. Dense whorls of branches that had developed on scaffold branches close to the trunk were thinned to outside branches to encourage horizontal growth. Long unbranched scaffolds were tipped to promote branching and development of flowering wood. After August 2007 trees were pruned in November 2007, March and September 2008, and April 2009. At the final pruning the uppermost node of the central leader of many trees could no longer be reached from the ground.

The four treatments (two varieties x two training systems) were arranged in a randomised complete block design, with five blocks, one plot of each treatment per block, and each plot comprising 4 x 4 trees (i.e. 16 trees in a rectangular arrangement). Yield and fruit quality measurements were made on the fully buffered central four trees of each plot.

The fresh weights of prunings were measured at each pruning time except at the remediation pruning in August 2007. In November 2007 the prunings were also dried at 60°C and weighed.

Tree height was measured in July-September from 2008 to 2013 and canopy width was measured in January 2009 and in June-July from 2009 to 2012. Canopy widths were not measured in 2013 because the trees were side hedged in December 2012 to maintain machinery access. Flower racemes were counted around anthesis in 2010 and 2011. Fruit were harvested from the trees in April 2011, and from the ground in 2012 and 2013, at approximately monthly intervals from April until September.

The harvested fruit were dehusked and samples of 100 nuts were taken from each plot to determine moisture content, based on a standard drying sequence of 2 days at 38 °C, 2 days at 45 °C and 2 days at 60 °C. The moisture content was used to calculate yields and average ‘nut-in-shell’ (NIS) weights at 10% moisture content, which is the industry standard.

In 2013, the fruit were further assessed for kernel recovery, the percentage of unsound kernel and the percentage of first grade kernel. Kernel recovery is the kernel weight expressed as a percentage of the total NIS weight. Unsound kernel is kernel affected by insect damage, mould or decay, or characterised by immaturity, discolouration, germination or rancidity (Anonymous 1995) and is expressed relative to the NIS on a percentage weight by weight basis. First grade kernel is sound kernel with an oil content of 72% or more, based on whether or not it floats in tap water (Mason and Wills 1983) and is expressed relative to the total sound kernel weight on a percentage weight by weight basis.

All the trees in the trial, including all the buffer trees in the plots, were assessed for storm damage on 25 May 2009 and on 29 January 2013, each time shortly after a severe storm.

Linear mixed models were used to explain trait variability, according to fixed effects of variety, pruning, season and their interactions. Spatial variability in the orchard was estimated by random effects associated with row position and column position. Potential correlation between repeat measures on each plot was accommodated by inclusion of random plot effects. Raceme counts were analysed on the logarithmic scale to force compliance with assumptions of the analysis. Null hypothesis significance tests for the fixed effects were conducted by calculation of F-ratio statistics. The models were used to predict average levels and standard error of each trait for each variety, pruning practice and season. Estimates of least significant difference at 5% critical value were also calculated to enable statistical inference for specific effects. Statistical analyses were conducted in the R environment (R core team 2013) including tools from the asreml package (Butler *et al*. 2009).

Storm damage, representing the number of trees lodged, split or snapped, was analysed using the G-test with the William's correction (Sokal and Rohlf 1995).

Results

The control trees and the trees trained to a central leader were pruned in the same fashion on the first pruning date, with similar amounts of material removed from both treatments (Table 1.1). Thereafter only the trained trees were pruned, with a small remediation pruning in August 2007 (data not shown) and more intensive pruning on four later occasions (Table 1.1). In total, about 8-times more material was removed from the central leader trees than from the control trees.

The early yields of the central leader trees were consistently lower than those of the control trees. Statistically important ($P < 0.05$) reductions in average yield due to pruning were detected in 2011 for the '246' trees and in 2012 for the '816' trees (Table 1.2). Statistically significant increases in average yield over time were detected within all varieties and treatments ($P < 0.05$) which was at least partly related to the maturation of the trees. There was a significant interaction effect ($P < 0.05$) of variety and season. This may have been related to the earlier commencement of production in '246'.

The cumulative yields of the trained trees over the first three years of production were 16% lower than the control trees for ‘246’ and 23% lower for ‘816’ (Table 1.2). The cumulative yields of ‘246’ were 67% higher than those of ‘816’ (Table 1.2).

The fruit harvested in one year was set from the flowering in the previous year (e.g. the 2011 harvest was set at flowering in 2010). There was more flowering in the control trees than in the central leader trees ($P < 0.05$; Table 1.2) and more flowering in ‘246’ than in ‘816’ ($P < 0.05$), consistent with the trends in yields. There was also a significant seasonal effect ($P < 0.05$), and a significant variety × season interaction ($P < 0.05$), again consistent with the trends in yields.

With respect to average NIS weights (Table 1.2), nuts from ‘246’ were significantly lighter than those from ‘816’ ($P < 0.05$). Small (< 1 g) but statistically important increases in nut size over time were observed ($P < 0.05$). Varietal differences were inconsistent over the three seasons as evidenced by a significant interaction ($P < 0.05$). No effect of early tree training was detected ($P < 0.05$).

There was no effect of early tree training on kernel recovery or the percentages of first grade or unsound kernel in 2013 ($P > 0.05$; Table 1.3). ‘816’ had higher kernel recovery and a higher percentage of first grade kernel than ‘246’ ($P < 0.05$).

Tree heights were unaffected by early tree training ($P > 0.05$; Table 1.4) and were similar for the two varieties ($P > 0.05$).

Early tree training affected canopy widths across and along the row (Table 1.4). In essence, early tree training reduced the widths of the canopies, but the central leader trees had much the same dimensions as the control trees by the end of the experiment. Canopy widths were similar for the two varieties ($P > 0.05$).

The control trees of ‘816’ sustained more storm damage than the ‘816’ trees trained to a central leader ($P < 0.05$), with 35 of the 80 control trees lodged and 2 snapped or split, and 22 of the 80 trained trees lodged and 3 snapped or split. Early tree training had no effect on the extent of storm damage in ‘246’ ($P > 0.05$), with 26 of the 80 control trees lodged and 5 snapped, and 32 of the 80 trained trees lodged and none snapped.

By the end of the study about 20% of the '246' and '816' trees initially trained to a central leader had developed co-dominant leaders.

Discussion

The early tree training of macadamia to a central leader resulted in an 18% reduction in yield over the first three years of production, averaged over the two varieties (Table 1.2). Part of the reason for this seems to be related to the flowering habit of macadamia. Macadamia tends to flower on less vigorous branches (Wilkie *et al*. 2009) in the shadier parts of the canopy (Olesen *et al*. 2011). Central leader training involves the removal of subordinate branches, which improves the illumination of the remaining branches. For macadamia, this might be paraphrased as removing fruiting wood and making the canopy environment less conducive for flowering. There was evidence for this in the raceme numbers per tree (Table 1.2), with more flowering on the control trees than on the pruned trees in both 2010 and 2011.

The response of young macadamia trees to training was similar to that for the training of trees in the early years of production. Olesen *et al*. (2011) found that light selective limb removal in 6-year-old '849' trees resulted in a yield penalty, while pruning to a central leader resulted in an even greater penalty.

Early tree training reduced the size of the canopies (Table 1.4) and this too might have had a detrimental effect on yields, given that macadamia production tends to increase with increasing orchard light interception (McFadyen *et al*. 2004 & 2013).

That the trained trees had lower crop loads than the control trees may help explain why the trained trees achieved canopy sizes similar to those of the control trees by the end of the experiment because crop load is negatively correlated with branch elongation (Wilkie 2009).

Early tree training had no detectable effect on the measured nut characteristics: average NIS weight, kernel recovery or the percentages of first grade or unsound kernel (Table 1.3).

The cropping pattern of the trees in our study was typical of that of commercial orchards, with no yield in the first few years after planting, then an exponential increase in yield in the first few years of production. However, macadamia does have large year to year variations in yield (McFadyen *et al*. 2004 & 2013) and it is not clear the extent to which these have distorted the developmental response. The side-hedging in December 2012 may have reduced crop loads in 2013 through competition effects between post-hedging vegetative flush development and early fruit set, and through reductions in canopy size and thus carbon assimilation (McFadyen *et al*. 2012).

The yields of '246' were greater than those of '816' on trees of a similar size (Tables 1.2 & 1.4). However, '816' does have some traits that might commend it, including a larger NIS weight (Table 1.2), a higher kernel recovery and a higher percentage of first grade kernel (Table 1.3).

Early tree training to a central leader improved the resistance of the upright variety '816' to storm damage, but had little effect on the susceptibility of the more spreading variety '246'. Most of the damage was in the form of the lodging of trees, which crudely equates with the drag of the whole canopy. The incidence of tree snapping or splitting, two quite different forms of mechanical failure, was too low to analyse separately.

In summary, the current industry recommendation of training young trees to a central leader ought to be reconsidered. Minimal pruning of young trees, to remove poor crotch angles for the sake of structural stability, appears to be a better option.

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Table 1.1. Fresh weights of prunings for minimally pruned control trees and trees that received early training to a central leader, for macadamia varieties '246' and '816'

These results were initially presented in MC09003 (McFadyen *et al*. 2011).

	Fresh weights of prunings (g)				
	2007 June	2007 November	2008 March	2008 September	2009 April
'246'					
Control	154				
Central leader	141	34	310	127	687
'816'					
Control	186				
Central leader	193	46	300	118	649

Table 1.2. Yields and raceme numbers for minimally pruned control trees and trees that received early training to a central leader, for macadamia varieties '246' and '816'

The least significant difference (lsd) at the 5% level is given for each trait as is the standard error (se).

	2010	2011	2012	2013	Total
Yields per tree (kg NIS)					
'246'					
Control		3.2	4.9	10.5	18.5
Central leader		1.8	4.4	9.4	15.6
'816'					
Control		0.6	4.8	6.0	11.5
Central leader		0.2	3.0	5.8	8.9
lsd = 1.3					
se = 0.5					
se for totals = 0.9					
Racemes per tree (with natural logarithms of counts in brackets)					
'246'					
Control	255 (5.5)	1719 (7.4)			
Central leader	174 (4.9)	1336 (7.2)			
'816'					
Control	19 (2.9)	551 (6.2)			
Central leader	6 (1.7)	295 (5.6)			
lsd = (0.4)					
se = (0.2)					
Average NIS weight (g)					
'246'					
Control		7.1	7.3	7.9	
Central leader		7.2	7.3	7.8	
'816'					
Control		8.2	8.0	8.6	
Central leader		8.3	8.1	8.7	
lsd = 0.2					
se = 0.1					

Table 1.3. Kernel recovery and the percentages of first grade and unsound kernel in 2013 for minimally pruned control trees and trees that received early training to a central leader, for macadamia varieties '246' and '816'

The least significant difference (lsd) at the 5% level is given for each trait as is the standard error (se).

	Kernel recovery (%)	First grade kernel (%)	Unsound kernel (%)
'246'			
Control	34.0	96.2	0.4
Central leader	34.1	96.4	0.5
'816'			
Control	35.5	99.1	0.4
Central leader	35.7	99.1	0.6
lsd	1.2	2.4	0.5
se	0.5	0.2	0.9

Table 1.4. Tree heights and canopy widths for minimally pruned control trees and trees that received early training to a central leader, for macadamia varieties '246' and '816'

The least significant difference (lsd) at the 5% level is given for each trait as is the standard error (se).

	2008	2009 January	2009	2010	2011	2012	2013
Tree height (m)							
'246'							
Control	1.8		2.7	3.4	4.2	4.6	5.1
Central leader	1.8		2.6	3.6	4.3	4.7	5.1
'816'							
Control	1.8		2.6	3.4	4.2	4.7	5.2
Central leader	1.8		2.5	3.5	4.3	4.8	5.3
lsd = 0.3							
se = 0.1							
Canopy width across row (m)							
'246'							
Control		1.2	1.7	2.6	3.7	4.3	
Central leader		1.0	1.3	2.4	3.4	4.2	
'816'							
Control		1.3	1.7	2.5	3.5	4.1	
Central leader		1.0	1.3	2.3	3.4	4.2	
lsd = 0.2							
se = 0.1							
Canopy width along row (m)							
'246'							
Control		1.3	1.7	2.8	3.6	3.9	
Central leader		1.0	1.4	2.5	3.5	3.9	
'816'							
Control		1.4	1.7	2.7	3.5	3.8	
Central leader		1.0	1.4	2.5	3.4	3.8	
lsd = 0.2							
se = 0.1							

Chapter 2

Effects of root pruning on the shoot growth and fruit production of macadamia

Introduction

Root pruning is a method for slowing the vegetative growth of horticultural trees (Geisler and Ferree 1984; Yang *et al*. 2012). The effects on yield depend on the way in which root pruning is applied, with reports of increases, decreases and no changes in yield.

The method is crude, with extensive short and long term effects on the physiology of the trees. Functions affected include the uptake of water (Black *et al*. 2012) and nutrients (Yang *et al*. 2012), photosynthesis and stomatal conductance (Black *et al*. 2012; Du *et al*. 2012; Yang *et al*. 2012), the production of plant growth regulators (Du *et al*. 2012; Yang *et al*. 2012) and the leaching of pesticide residues from the plants into the soil (Yang *et al*. 2012).

Here we present the results of the first investigation into the effects of root pruning on the shoot growth and fruit production of macadamia. The work was initiated and funded by NSW DPI to complement the work in projects MC09003 and MC11000.

Materials and methods

Two experiments on the effects of root pruning on the yield and canopy development of macadamia were established at the Centre for Tropical Horticulture, Alstonville (28.9°S, 153.5°E) in September 2009, one on 7-year-old trees of variety ‘849’, the other on 12-year-old trees of variety ‘A4’. In our experiments trees were root pruned with a trench digger to a depth of 0.6 m. Trenches were dug parallel with the tree row at 1-1.2 m from the trunk on both sides of the tree.

'849'

Twelve plots of 3 trees were restrictively randomised to two 6-plot treatments based on previous management history. One treatment was a control, and the soil around the trees of this treatment was not disturbed. The other treatment was root pruned, with trenches dug alongside the trees of this treatment as described above.

The trees were first root pruned on September 24, 2009. Also on September 24, 2009 both the control and root pruned trees were side-hedged. After hedging, 10 headed branches per tree were tagged. These branches were monitored over the next few months for the number and final length of all new shoots on the first and second post-hedging flushes.

For each plot, fruit were harvested from the ground between March and August 2010 at approximately monthly intervals then de-husked. After de-husking, samples were taken for each plot to determine moisture content so that yields could be expressed at 10% moisture content. The samples were also used to determine average 'nut-in-shell' (NIS) weight at 10% moisture content.

The trees were root pruned for a second time on February 8, 2011 and then again on February 10, 2012. Fruit were harvested and processed for the 2011 and 2012 seasons as above. Fruit from the 2012 harvest were further processed to determine kernel recovery, and the percentages of first grade kernel and unsound kernel, as calculated in Chapter 1.

'A4'

Eighteen individual trees were restrictively randomised to two 9-tree treatments based on tree size and previous management history. One treatment was the control, the other was root pruned. Root pruning occurred on September 15, 2009; February 7, 2011; and January 11, 2012. Immediately following root pruning in 2009, ten branches towards the top of each tree were tagged and monitored for subsequent shoot development as in the previous experiment. The tagging and monitoring was repeated following root pruning in 2011. Harvesting and processing was undertaken as in the previous experiment.

The results from both experiments were analysed by analysis of variance in SigmaStat (Systat Software, San Jose, CA, USA).

Results

'849'

The yields were not significantly different ($P > 0.05$; Table 2.1) between the control trees and the root pruned trees in 2010, 2011 or 2012, nor was there a significant difference in the cumulative yields over the three years. The yields in 2012 were greater than those in 2010 and 2011 ($P < 0.05$). The yields in 2010 and 2011 were approximately the same ($P > 0.05$).

Overall, the NIS weights of the root pruned trees were approximately 3% greater than those of the control trees ($P < 0.05$; Table 2.1). The NIS weights were approximately the same between years ($P > 0.05$).

The kernel recoveries and percentages of first grade and unsound kernel were similar for the two treatments in the 2012 harvest ($P > 0.05$; Table 2.1).

The numbers of shoots to develop on the first and second flushes following side-hedging on September 24, 2009 were similar for the control trees and the root pruned trees ($P > 0.05$; Table 2.2), with more new shoots on the second flush than on the first ($P < 0.05$).

The lengths of the new shoots to develop on the first and second flushes following side-hedging on September 24, 2009 were shorter for the root pruned trees than for the control trees ($P < 0.05$; Table 2.2) and shorter on the first than the second flush ($P < 0.05$).

'A4'

The yields were not significantly different ($P > 0.05$; Table 2.3) between the control trees and the root pruned trees in 2010, 2011 or 2012, nor was there a significant difference in the cumulative yields over the three years. The yields in 2012 were smaller than those in 2010 and 2011 ($P < 0.05$). The yields in 2010 and 2011 were approximately the same ($P > 0.05$).

The NIS weights of the root pruned trees were similar to those of the control trees ($P > 0.05$; Table 2.3). The NIS weights in 2012 were lower than those in 2010 and 2011 ($P < 0.05$). No difference in NIS weight was detected in 2010 and 2011 ($P > 0.05$).

The kernel recoveries and percentages of first grade and unsound kernel were similar for the two treatments in the 2012 harvest ($P > 0.05$; Table 2.3).

The numbers of shoots to develop on the first and second flushes following root pruning on September 15, 2009 were similar for the control trees and the root pruned trees ($P > 0.05$; Table 2.4), with fewer new shoots on the second flush than on the first ($P < 0.05$).

The numbers of shoots to develop on the first and second flushes following root pruning on February 7, 2011 were similar for the control trees and the root pruned trees ($P > 0.05$; Table 2.4), with similar numbers of new shoots on the first and second flushes ($P > 0.05$).

The lengths of the new shoots to develop on the first and second flushes following root pruning on September 15, 2009 were similar for the control trees and the root pruned trees ($P > 0.05$; Table 2.4). The new shoots on the first flush were shorter than those on the second flush ($P < 0.05$).

The lengths of the new shoots to develop on the first and second flushes following root pruning on February 7, 2011 were shorter for the root pruned trees than for the control trees ($P < 0.05$; Table 2.4) and shorter on the first than the second flush ($P < 0.05$).

Discussion

Root pruning is an effective means of reducing shoot length in macadamia. In '849' the shoot lengths on the first flush following the first round of root pruning were 33% shorter than those on the control trees, while the shoots on the second flush were 9% shorter (Table 2.2). In 'A4', while there was no evidence of an effect of root pruning on shoot development after the first round of root pruning, there was after the second round, with 26% shorter shoots on the first flush and 17% shorter shoots on the second flush (Table 2.4). Two flushes of vegetative growth take a few months to complete (Wilkie *et al*. 2009) so the results indicate a persistent effect of root pruning. This is consistent with work on Chinese jujube where effects on shoot length were evident in the second season following root pruning (Yang *et al*. 2012).

No effects of root pruning on yields or nut characteristics were detected, except for a slight increase in NIS weight in '849' (Tables 2.1 & 2.3).

Shoot lengths were consistently shorter on the first than on the second flush (Tables 2.2 & 2.4) against backgrounds of greater ('A4'), similar ('A4') or fewer ('849') shoot numbers, and for different times of the year (spring-summer or late summer-autumn shoot development for 'A4'). The results for the spring-summer monitored 'A4' and '849' trees are at odds with the findings of Wilkie *et al*. (2009) and McFadyen *et al*. (2012) who found shorter shoot lengths in the warmer months. The reasons for the differences are unclear but may partly relate to the higher shoot numbers on the first flush for the 'A4' trees, and to the severity of hedging for the '849' trees.

Root pruning appears to be a useful technique for reducing the frequency of pruning and hedging in macadamia orchards. The method we employed for experimental purposes is too labour intensive for commercial purposes, so more work is needed to assess the effects of root pruning by a tractor-mounted blade.

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Table 2.1. Effects of root pruning on the yields and fruit characteristics of macadamia variety '849'

Each treatment comprised six 3-tree plots. Statistical comparisons are made in the Results section.

	Yield (NIS kg/tree)	NIS weight (g)	Kernel recovery (%)	First grade kernel (%)	Unsound kernel (%)
2010					
Control	5.2	7.0			
Root pruned	5.7	7.2			
2011					
Control	6.4	7.1			
Root pruned	4.7	7.6			
2012					
Control	7.4	7.2	43.8	87.8	5.4
Root pruned	8.7	7.2	44.3	89.3	4.9
Standard errors	0.7	0.11	0.2	0.9	0.4

Table 2.2. Shoot development of the first two flushes following root pruning in 2009, for macadamia variety '849'

Each treatment comprised six 3-tree plots. Ten headed branches were monitored for each tree. Statistical comparisons are made in the Results section.

	Shoot number per branch	Average shoot length (mm)
First flush		
Control	3.3	61.1
Root pruned	2.7	40.9
Second flush		
Control	3.6	143.6
Root pruned	3.4	130.4
Standard errors	0.15	5.3

Table 2.3. Effects of root pruning on the yields and fruit characteristics of macadamia variety 'A4'

Each treatment comprised nine individual trees. Statistical comparisons are made in the Results section.

	Yield (NIS kg/tree)	NIS weight (g)	Kernel recovery (%)	First grade kernel (%)	Unsound kernel (%)
2010					
Control	12.9	9.3			
Root pruned	11.3	9.2			
2011					
Control	11.6	9.0			
Root pruned	9.4	9.0			
2012					
Control	5.3	8.2	43.6	96.5	1.7
Root pruned	4.2	8.1	44.2	97.6	2.2
Standard errors	0.9	0.12	0.3	1.2	0.2

Table 2.4. Shoot development of the first two flushes following root pruning in 2009, for macadamia variety 'A4', and then again following a second root pruning in 2011

Each treatment comprised nine individual trees. Ten branches were monitored for each tree. Statistical comparisons are made in the Results section.

	Shoot number per branch	Average shoot length (mm)
Root pruned September 2009		
First flush		
Control	1.3	106.0
Root pruned	1.3	122.9
Second flush		
Control	0.6	202.8
Root pruned	0.3	203.3
Standard errors	0.12	12
Root pruned February 2011		
First flush		
Control	1.6	116.8
Root pruned	1.2	86.3
Second flush		
Control	1.4	152.0
Root pruned	1.1	126.4
Standard errors	0.11	6.5

Chapter 3

Effects of trunk girdling on the shoot growth and fruit production of macadamia

Introduction

Trunk girdling is commonly used in horticulture to increase tree yields and to suppress vegetative shoot development (McFadyen *et al*. 2013). It involves the removal of a narrow ring of phloem from around the trunk, restricting the flow of carbohydrates and plant growth regulators from the canopy to the roots, without affecting the flow of water from the roots to the canopy. It needs to be used judiciously. As a form of ring-barking it has the potential to weaken or kill trees.

As with root-pruning in the previous chapter, girdling is a crude intervention that affects a broad range of plant functions. Carbohydrates tend to accumulate above the girdle (Cormack and Bate 1976) and photosynthesis and stomatal conductance tend to decrease (Sellin *et al*. 2013), possibly because of feedback inhibition from the elevated levels of carbohydrates. Respiration rates increase above the girdle and decrease below the girdle (Domec and Pruyn 2008) and the metabolism of plant growth regulators is also affected (Kong *et al*. 2012).

There has been little research on the use of trunk girdling for the production of macadamia. Stephenson *et al*. (1989) used a very narrow girdle (1 mm) and found no significant effect on yield. McFadyen *et al*. (2013) used a somewhat wider girdle (6 mm) and found no significant effect on yield in one study, and a variable response to repeated girdling over several seasons in a second study. Here we extend the second study by McFadyen *et al*. (2013) to a fifth season, and analyse the cumulative effects of girdling on yield and tree size across the whole study. The study in question was established and maintained in the first instance by NSW DPI using departmental funds. After the first year, the study was funded by NSW DPI, Horticulture Australia

Limited and levy contributions from the Australian macadamia industry through MC09003 (McFadyen *et al*. 2011).

Materials and methods

The experiment was conducted at the Centre for Tropical Horticulture (CTH) at Alstonville in northern New South Wales (28.9°S, 153.5°E). The soil at the CTH is deep, well-drained, reddish-brown clay (Morand, 1994). The climate is subtropical. The mean maximum temperature ranges from 18.6°C in July to 27.2°C in January, and the mean minimum temperature ranges from 9.9°C in July to 19.5°C in January. The mean annual rainfall is 1825 mm.

The experiment was carried out on trees of variety ‘849’ planted in 1998. Treatments were randomly allocated to paired plots, which each comprised three trees. Eight replications per treatment were distributed across 10 rows. Plots were buffered within the row and in adjacent rows by untreated trees of variety ‘246’.

Trees were girdled during anthesis on 28 August 2008 and 1 September 2009, allowed to rest in 2010, and girdled again during anthesis on 19 September 2011 and 11 September 2012. The trees were girdled using a small electrical router (Ryobi EVT400K, Techtronic Industries Australia Pty Ltd., Doncaster, Victoria, Australia) to remove a ring of bark, 6 mm wide, from around the whole trunk. Non-girdled trees served as controls.

Tree heights were measured just before the first girdling and then at approximately12-month intervals up to July 2013. Standard side-hedging with a commercial hedging machine to maintain the inter-row for orchard management was applied to both treatments on 23 November 2009, 12 September 2011 and 4 December 2012. Fruit were harvested from the ground at 3- to 4-week intervals between March and September from 2009 to 2013, and processed as per Chapter 1. Kernel recoveries and the percentages of first grade and unsound kernel were estimated at the second harvest in each season.

Linear mixed models were used to explain variability in each trait as classified by fixed effects of treatment, season and their interaction. Spatial variability in the orchard was estimated by random effects associated with blocks. Null hypothesis tests for the fixed effects were conducted by calculation of F-ratio statistics. The models were used to predict the average and standard error for each trait, for each treatment and season. Estimates of least significant difference at 5% critical value were also calculated to enable statistical inference for effect sizes. Statistical analyses were conducted in the R environment (R core team 2013) including tools from the asreml package (Butler *et al*. 2009).

Results

The yields of the girdled trees were not significantly different from those of the controls in the four seasons in which the trees were girdled ($P > 0.05$; Table 3.1). In 2011, the one season in which the girdled trees were not girdled, the yields of the girdled trees were lower than those of the controls ($P < 0.05$).

The cumulative yields across the whole study were approximately the same (65.8 versus 65.0 kg NIS per tree, girdled versus control, standard error = 2.7; i.e. approximately 1% higher in the girdled trees; $P > 0.05$). The cumulative yields for just the four seasons in which trees were girdled were also approximately the same (52.2 versus 49.4 kg NIS per tree, girdled versus control, standard error = 2.3; i.e. approximately 6% higher in the girdled trees; $P > 0.05$).

With respect to average NIS weights, there were lower weights for the girdled trees in the four years in which the trees were girdled ($P < 0.05$; Table 3.1), but no significant difference in weights in 2011 when the girdled trees were not girdled ($P > 0.05$).

In 2012 the kernel recovery and percentage of first grade kernel were lower in the control trees than in the girdled trees ($P < 0.05$; Table 3.1). There were no significant differences between treatments in these two characteristics in the other years ($P > 0.05$).

There were no significant differences between treatments with respect to the percentage of unsound kernel ($P < 0.05$; Table 3.1).
For yield, average NIS weight, kernel recovery and the percentages of first grade and unsound kernel, there were significant differences between seasons ($P < 0.05$; Table 3.1).

By the end of the experiment the control trees were significantly taller than the girdled trees by 0.4 m ($P < 0.05$; Table 3.1).

Discussion

Macadamia production tends to increase with increasing tree size up to very high levels of orchard light interception (McFadyen *et al*. 2004 & 2013). Given that the girdled trees were smaller than the control trees but had comparable cumulative yields (Table 3.1) girdling appears to have increased the efficiency with which the canopies produced fruit. There is further support in that the yields of the girdled trees were lower than those of the control trees in 2011, the one season in which the girdling treatment was not applied to the girdled trees. Krezdorn and Wiltbank (1968) found a similar effect for tangelo, where the cessation of girdling often reduced yields relative to trees that continued to be girdled, to levels similar to those of control trees. However, the reason our trees were rested was because the leaves looked somewhat yellow and sparse, so that our lower yields may have related to tree health.

In the harvest following the first application of the trunk girdles, the girdled trees held a non-significant 8% more crop than the control trees. This compared with a non-significant 13% increase in yield for girdled trees in a similar experiment on the same variety ('849'), in the same year using the same girdle width (6 mm; McFadyen *et al*. 2013); and a non-significant 7% increase in girdled trees of variety 'Own Choice' using a 1 mm girdle (Stephenson *et al*. 1989). These increases were low compared with those for citrus (73-400%; Krezdorn and Wiltbank 1968; De Lange *et al*. 1974; Barry and Bower 1997; Rivas *et al*. 2007) and lychee (35%; Roe *et al*. 1997). The reason for this may be the preponderance of rays (horizontal, radial lines of living cells) in macadamia wood, the heights of which are similar to the widths of our girdles (6 mm). These rays may have provided pathways for the leakage of solutes around the girdles (McFadyen *et al*. 2013).

In terms of cumulative yields, there were no significant differences between the girdled trees and the control trees across the whole five years of the study, or for those four seasons in which the trees were girdled. In contrast, the cumulative effect of girdling ‘Orlando’ tangelo over four years was to increase yields by 65% (Krezdorn and Wiltbank 1968).

In our experiment girdling restricted the proportions of branches with new flushes, the numbers of new shoots per branch, and the lengths of those shoots (McFadyen *et al*. 2013) and, by the end of the experiment, had significantly restricted the heights of the trees (Table 3.1). Given that carbohydrate concentrations tend to be elevated above girdles (Cormack and Bate 1976), changes to the metabolism of plant growth regulators may have played an important role in the restriction of vegetative growth. Plant nutrition may also have been a factor given, for example, the major role amino acids play in the translocation of nitrogen in macadamia, and the likely interactions between the phloem and xylem in such translocation (Fletcher 2001).

In the four seasons in which the girdles were applied the average NIS weight was lower for the girdled trees (Table 3.1). Given that the girdled trees were holding yields similar to those of the control trees on smaller canopies, it may be that the effect was related to greater carbon limitation to NIS growth in the girdled trees. Wilkie (2009) varied the crop load of macadamia by raceme removal at anthesis and found that that average NIS weight decreased with increasing fruit density.

There were only minor differences in the other nut characteristics, with a slightly higher kernel recovery for the girdled trees in 2012, and a slightly higher percentage of first grade kernel for the girdled trees in the same year (Table 3.1).

Girdling is at very least an effective means of restricting the growth of macadamia, thereby reducing the frequency of canopy management interventions. The effects, to date, on increasing yields have been weak, but these might be improved with better techniques. The obvious next step would be to test a range of girdle widths and depths.

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Table 3.1. Yields, nut characteristics and tree heights for control trees and trees that were girdled at anthesis in 2008, 2009, 2011 and 2012, but not in 2010

The least significant difference (lsd) at the 5% level is given for each trait as is the standard error (se).

	2008	2009	2010	2011	2012	2013
Yields per tree (kg NIS)						
Control		14.3	10.7	15.6	12.5	11.9
Girdled		15.5	10.0	13.6	13.6	13.1
lsd = 1.9						
se = 0.7						
Average NIS weight (g)						
Control		7.15	7.63	7.35	7.32	7.90
Girdled		6.89	7.14	7.42	7.10	7.65
lsd = 0.18						
se = 0.06						
Kernel recovery (%)						
Control		44.9	44.5	42.7	40.1	40.8
Girdled		44.6	43.6	43.2	41.7	40.5
lsd = 1.0						
se = 0.4						
First grade kernel (%)						
Control		92.7	95.7	92.5	83.3	83.2
Girdled		93.0	94.7	94.3	87.5	79.6
lsd = 3.7						
se = 1.3						
Unsound kernel (%)						
Control		9.4	4.1	3.8	5.6	6.5
Girdled		10.1	4.4	4.2	5.9	6.3
lsd = 1.7						
se = 0.7						
Tree height (m)						
Control	6.9	7.2	7.4	7.5	7.7	7.9
Girdled	7.0	7.2	7.2	7.3	7.5	7.5
lsd = 0.3						
se = 0.1						

Chapter 4

Responses of macadamia to the timing of annual hedging across four seasons

Introduction

Macadamia is native to the subtropical parts of the eastern seaboard of Australia, but is grown commercially for its edible kernel in a wide range of countries. In Australian orchards the trees are typically grown in hedgerows, with the trees side-hedged in early spring, around the time of anthesis, for ease of management, not for improved productivity (McFadyen *et al*. 2013). Hedging at this time, however, causes accentuated fruit drop, which seems to be largely related to competition between post-hedging shoot development and early fruit set, but to a lesser extent also related to the reduced carbon availability caused by the loss of canopy (McFadyen *et al*. 2011b).

Hedging at other times may be a way of mitigating the yield loss. Hedging in late autumn or early winter seems to be one possibility, allowing some regeneration of the canopy following hedging but before anthesis, and delaying the second post-hedging flush until after fruit set. Such a strategy has been successful at either improving yields or reducing fruit drop in one study, but decreased yields in a second study (McFadyen *et al*. 2012). In a third study, hedging at this time maintained yields relative to a non-hedged control (Wilkie *et al*. 2010).

A second option is to delay hedging until after fruit set, when the fruit are less prone to abscission, in late spring or summer. This strategy substantially improved yields relative to trees hedged at anthesis in four studies, but not in a fifth (McFadyen *et al*. 2012).

The results cited above relate to experiments run for one year. There are good reasons to suspect that the yield responses to hedging at different times of year would be more complex if examined over several seasons. There is, for example, enormous season to season variability in yields (McFadyen *et al*. 2004) much of which probably relates to weather (eg Wilkie *et al*. 2010) but some of which also relates to true bienniality (Wilkie 2009). There are also potential influences of the hedging times on flowering, either through an effect on the phase of the cycle of flush development (Olesen 2005; Wilkie *et al*. 2010) or on the availability of carbohydrates for growth (McFadyen *et al*. 2012) or on the size and number of shoots (Wilkie *et al*. 2009). There are also good reasons to suspect that the relative distribution of flowers and fruit within the canopy change as trees and orchards age, even though there is little in the way of data to support this. Salter *et al*. (2005) did find that the distance from branch tip to first flower tended to decrease across a range of macadamia varieties as the trees aged from 5 to 7 years. Changes in the distribution of flowers and fruit might affect tree responses to canopy management practices.

Our purpose then was to examine the effects of annual hedging on large trees at different times of the year across four seasons, on yields and nut characteristics. The work was conducted in a mature commercial orchard using the macadamia variety '344'. The work began under MC09003 and a report on the first two years of the study was given in the final report for that project (McFadyen *et al*. 2011a). For completeness, the results of the whole trial are presented here.

Materials and methods

Experimental design

The work was conducted in a 20-year-old commercial orchard at Eureka (29.08°S, 146.20°E) in northern New South Wales, planted on a deep, well-drained reddish brown clay loam (Morand 1994). The orchard mostly comprised alternate rows of varieties '344' and '741', aligned north-south with 10 m between the rows and 3 m between the trees within the row. The orchard was managed according to industry guidelines (O'Hare *et al.* 2004).

The trial was established in 2009 using variety '344'. Across 8 rows, 45 plots of 3 adjacent trees were selected. Each plot was buffered by at least one tree, treated in the same fashion as the plot trees, on either side within the row, and by adjacent rows of variety '741', which were side-hedged annually in the spring. The plots were restrictively randomised to 5 treatments: a control that was not hedged during the course of the experiment and 4 annual side-hedging regimes timed for June, September, December or February (the following year); such that there were 9 plots per treatment.

A commercial hedger was used to apply the hedging treatments. Three cuts were made on each side of the hedgerow: two vertical cuts on the lower part of the canopy and a third cut at the top of the canopy angled slightly towards the centre of the row.

After each hedging, trees were visited regularly to note the approximate time of post-hedging bud release, and to make qualitative assessments of the progress of post-hedging flush development, the stage of flower development, and the degree of fruit set.

Fruit were harvested from the ground between March and August at 4- to 6-week intervals, and processed as per Chapter 1. Kernel recoveries and the percentages of first grade and unsound kernel were estimated at the first harvest in each season.

Statistical analyses

The original 9 plots per treatment were reduced to 7 plots per treatment owing to problems with tree health, or to miscommunication with the harvesting contractor, which resulted in incomplete harvest records for some plots. Linear mixed models were used to estimate fixed effects of treatment, season and their interaction. Random effects due to the plots were estimated to account for the correlation between the repeated observations on each plot. Additional variation due to location in the orchard was examined by including random effects of row and tree position. The statistical importance of the fixed effects was assessed by Wald statistics and the random effects were tested by reduction in Akaike Information Criteria when compared with a model that excluded a spatial component. The models were used to predict average levels of each trait and their standard error for each treatment and season. Estimates of least significant difference at 5% critical value were also calculated to enable statistical inference for effect sizes. Statistical analyses were conducted in the R environment (R core team 2013) including tools from the asreml package (Butler *et al*. 2009).

Results

The canopies of the control trees became progressively larger than those of the hedged trees over the course of the experiment. The yields of the control trees were greater than those of the hedged trees in 2011 and 2013, and greater than all but those of the December hedged trees in 2012 ($P < 0.05$; Table 4.1).

The yields of the December hedged trees were greater than those of the September hedged trees in 2012, but lower than those of the September hedged trees in 2013 ($P < 0.05$; Table 4.1); otherwise there were no significant differences in yields between hedging times ($P > 0.05$).

There were significant seasonal differences in yield ($P < 0.05$; Table 4.1).

The average NIS weights of the September hedged trees were lower than those of all other treatments in 2010 and 2011, and lower than all the other hedge treatments in 2013 ($P < 0.05$; Table 4.1). There were strong seasonal differences in average NIS weight for all treatments ($P < 0.05$).

There were relatively few differences in kernel recovery and in the percentages of first grade and unsound kernel between treatments ($P < 0.05$; Table 4.1) but there were significant differences between seasons for all treatments for all three characteristics ($P < 0.05$).

Discussion

There was little evidence that time of hedging affected yields in large ‘344’ macadamia trees. The only result in line with expectations was in 2012, the year of the highest yields, where the yields of the trees hedged at anthesis in September were lower than those of the trees where hedging was delayed until December (Table 4.1). Against expectations, this result was reversed the following year.

McFadyen *et al*. (2012) found that December hedging increased yields in ‘344’ by 18% in 10-year-old trees and 54% in 17-year-old trees compared with September hedged trees. They also found that November-December hedging increased yields in ‘A4’ by 77% in 7-year-old trees and 95% in 10-year-old trees. However, for 17-year-old ‘A4’ trees they found that there were negligible differences in yield between December and September hedging. They speculated that the lack of response in the 17-year-old trees may have been due to the low initial fruit set, which might have reduced the competition for resources between fruit growth and post-pruning shoot growth.

In our experiment, on 20-year-old ‘344’ trees, yields were poor in three of the four seasons, and it may be that crop load was masking a time of hedging effect in these years in a similar fashion to that for the 17-year-old ‘A4’ trees mentioned above. In the one good season, 2012, December hedging increased yields by 23% compared with September hedging.

In 2013, December hedging decreased yields by 29% compared with September hedging. This might be evidence of true bienniality. Wilkie (2009) found that removing approximately 95% of racemes at anthesis reduced yields in the following harvest, increased the return flowering the following spring, and then increased the fruit density of the subsequent harvest by approximately 150%.

The control trees had much higher cumulative yields than the hedged trees. This was at least partly a function of the control trees developing progressively larger canopies. The control trees were not hedged over the course of the experiment, and their lateral growth would have been further promoted by the hedging of the adjacent buffer rows.

Macadamia tends to increase production up to very high levels of light interception (McFadyen *et al*. 2013).

In terms of nut characteristics, the only notable tendency was for September hedged trees to have smaller NIS weights. This might be an indication that carbon limitation to fruit growth during early fruit development, caused by both removal of part of the canopy and by competition with post-hedging regrowth, may affect final fruit size. However, McFadyen *et al*. (2012) found no such effect with varieties ‘816’ and ‘A38’ in comparisons of June and September hedging, nor with ‘A4’ in a trial with a control and four hedging times, where September hedged trees had the highest NIS weights.

Along with the complications outlined above in both the Introduction and the Discussion, there were other potentially confounding effects with the experiment, including leaf damage by thrips, leaf miners and monolepta beetles (McFadyen *et al*. 2011a). All these things taken together, there is need for much more work on the long term effects of time of hedging on production in large macadamia trees.

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Table 4.1. Yields and nut characteristics for trees subjected to different annual side-hedging regimes, or which were not hedged (control trees)

The side-hedged trees were hedged once annually, either in June, September, December or February (the following year). The least significant difference (lsd) at the 5% level is given for each trait as is the standard error (se).

	2010	2011	2012	2013
Yields per tree (kg NIS)				
Control	11.8	11.2	20.4	14.9
June	10.6	6.5	15.9	10.2
September	12.9	8.0	15.0	10.6
December	12.9	7.9	18.5	7.5
February	11.6	7.2	15.8	8.8
lsd = 3				
se = 1				
Average NIS weight (g)				
Control	8.2	7.5	7.0	8.2
June	8.1	7.6	6.9	8.4
September	7.6	7.1	6.9	8.0
December	8.0	7.5	6.7	8.4
February	7.9	7.6	6.7	8.4
lsd = 0.3				
se = 0.1				
Kernel recovery (%)				
Control	30.5	30.4	28.5	31.3
June	30.1	29.4	28.8	30.8
September	31.6	30.5	29.6	30.9
December	30.9	30.2	28.9	30.8
February	30.2	30.8	28.6	31.3
lsd = 1.1				
se = 0.5				
First grade kernel (%)				
Control	89.1	71.8	83.2	79.1
June	91.6	69.9	80.3	77.7
September	92.8	72.2	82.7	78.4
December	87.6	70.5	79.4	82.0
February	90.2	74.6	83.1	82.0
lsd = 5				
se = 1.9				
Unsound kernel (%)				
Control	2.9	5.1	2.5	2.0
June	3.4	5.4	2.0	2.9
September	3.3	5.1	1.9	3.0
December	3.8	5.4	2.8	3.8
February	2.7	5.8	2.8	1.7
lsd = 1				
se = 0.4				

Chapter 5

Miscellaneous activities

Introduction

In this chapter we briefly report on three other activities undertaken during the course of the project. The first of these involved two additional experiments on time of hedging. These experiments were established in 2012 in light of the equivocal results coming out of the time of hedging trial (2009-2013) reported in Chapter 4 and in an earlier report (McFadyen *et al*. 2011). The second involved the collection of yields from a demonstration block managed by a combination of selective limb removal and side-hedging. The third involved support for grower trials funded under a separate project (MC12011 with HAL).

Time of hedging

Trees of varieties ‘246’ and ‘849’ were side-hedged in September or November at the Centre for Tropical Horticulture (28.9°S, 153.5°E) in 2012, with the expectation that the yields of the September hedged trees would be lower than those for the November hedged trees because younger developing fruit are more likely to abscise in response to competition for carbon from the post-hedging vegetative flush than older fruit (McFadyen *et al*. 2012).

For ‘246’, five restrictively randomised rows were hedged in each month. For ‘849’, four such rows were hedged each month. Yields, kernel recoveries and percentages of first grade and unsound kernel were collected as per Chapter 1. The results were analysed using general linear models.

The yields for the September and November hedged trees were not significantly different for either cultivar ($P > 0.05$) although the expected trends were evident with

6% more nut-in-shell at 10% moisture content (NIS) on November hedged ‘246’ trees than on September hedged trees (14.04 versus 13.29 kg/tree) and 5% more NIS on the November hedged ‘849’ trees than on September hedged trees (7.10 versus 6.78 kg/tree).

There were no significant differences between hedging times in kernel recovery or in the percentages of first grade or unsound kernel for either experiment ($P < 0.05$).

Yields from demonstration block

An experiment on the effects of early combined topping/hedging/selective limb removal on the yields and canopy size of variety ‘849’, reported in McFadyen *et al*. (2011), was discontinued under the current project because of insufficient funds.

In late May 2011 the trial was converted into a demonstration block. All 76 trees in the original trial, which were up to 7 m in height, were brought down to 5 m using selective limb removal. The 2011 yield, before selective limb removal, was 1.8 tonnes NIS/ha. The 2012 yield, after selective limb removal, was 1.7 tonnes/ha.

In late May 2012, the trees were side-hedged and there was no additional selective limb removal. The subsequent 2013 yield was 2.5 tonnes/ha.

In late May 2013, the trees were bought down to 6 metres in height using selective limb removal, a metre higher than in 2011 due to concerns that there may be insufficient canopy to hold a satisfactory crop. The 2014 harvest will be collected under the new HAL project ‘Transforming subtropical/tropical tree crop productivity (AI13004)’.

The work undertaken in the demonstration block has been an important pilot study into the use of a combination of selective limb removal and side-hedging to keep macadamia trees small and productive. A formal trial of the new strategy will be established under AI13004 through the conversion of the early tree training trial reported in Chapter 1.

Support for 'Time of flowering and pollination relevant to orchard weather conditions in Northern NSW – a growers trial group (MC12011)'

We have supported the grower trial group through assistance with the design of canopy management trials; the collation of grower collected yields from the trials; the assessment of fruit quality; the provision of long term weather records for Alstonville; and through presentations and general feedback at grower group meetings.

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MacSmart website

NSW DPI has contributed several videos on the canopy management of macadamia to the MacSmart website, and made available to the website managers the above articles published in the Australian Macadamia Society News Bulletin, and the final report presented here, for incorporation in edited forms on the website.

Articles in scientific journals

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Recommendations

Commercial practices

(1) The macadamia industry should reconsider its recommendation to train young trees to a central leader because the practice can lead to a substantial yield penalty.

(2) Root pruning appears to be an effective means of controlling the vigour of macadamia trees, but growers should adopt the practice with caution because work with other crops has shown that overuse of the practice can compromise tree health.

(3) Girdling is also an effective means of controlling vigour. Based on the results from other crops, it might yet have a beneficial effect on yields. At 6 mm wide, our girdling may have been too narrow.

(4) The current industry recommendation for time of hedging is in late spring or early summer, instead of early spring. This recommendation stands. The overall weight of evidence points to a yield benefit, while the least supportive evidence is only that timing had no effect on yield.

Future research directions arising from the report

(1) More research is needed on root pruning, especially in relation to pruning techniques and the frequency of pruning.

(2) More research is needed into branch girdling, especially in relation to the width and the depth of the girdle.

(3) More research is needed into the relationship between time of hedging and crop load, including more research into biennial bearing and age related changes in the location of the crop within the canopy.

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