Chapter 7

General Discussion

The large size and dense canopy of mature macadamia trees result in heavily shaded and crowded orchards unless tree size is controlled. An ongoing concern has been that the shading causes yield decline but this has been demonstrated at only one site (McFadyen et al. 2004). Shading and crowding also create numerous management problems including loss of ground-cover and consequent soil erosion, slow orchard floor drying after rain resulting in harvest delays and deterioration in nut quality, greater pest and disease risk, and a reduced ability to spray trees effectively.

The aims of the research presented in this thesis were: to confirm yield trends for mature orchards; evaluate tree size control methods adopted by industry; and to investigate the effect of pruning on fruit set and develop methods to mitigate this effect in order to improve yield outcomes from pruning.

Chapter 2 reported results from a yield survey in mature orchards and from three pruning experiments. Yields in orchards with tree volumes corresponding to light interception levels in excess of 85% (McFadyen et al. 2004) declined by between 2%-3% per year for up to 10 years. This supported earlier conclusions on the occurrence of yield decline and that it occurred at high levels of orchard light interception but that it is small compared with inter-seasonal variation (McFadyen et al. 2004). This is significant because the initial industry perception had been that a substantial yield decline of around 50% due to crowding could occur over just two seasons (Trochoulias 1994). The results from this study reinforce the idea that seasonal variation has been confused with real yield change. However, although the
rate of yield decline was much less than early perceptions, it compounded to a substantial reduction over a 10-year period. This will significantly limit the industry’s ability to meet projected long-term forecasts for growth in production (Stephenson and Mayer 2009).

Yield decline was associated with increasing tree size and shading and the increase in yield in response to limb removal in one experiment in this chapter supported the view that light is a limiting factor. However it is also possible that declining soil health and increasing tree age (Day et al. 2001), both confounded with the level of shading, also contribute to yield decline. This may limit the extent to which yield decline can be prevented by tree size control strategies, but these are still essential for efficient orchard management.

Selective limb removal resulted in a short-term increase in yield in one experiment and decreased yield in another. In an earlier study, structural pruning in younger trees decreased yield in proportion to the amount of wood removed (Olesen et al. 2011). The variable response in macadamia to limb removal is consistent with responses reported for other crops. It is likely that removal of limbs increased light penetration to the remaining limbs and increased productivity of those limbs as observed for avocado (Thorp and Stowell 2001). However it appeared that the increase was not always large enough to compensate for the loss of fruiting wood and increase whole tree yield. Removal of a co-dominant leader created a large gap in the canopy and reduced yield. It is likely that the increase in light penetration was localised to the edges of the gap (Lombardini 2006) with the result that the overall increase in canopy light penetration was small relative to the amount of fruiting wood removed. A better option is to remove more, smaller limbs from throughout the
canopy, targeting the more vigorous branches which tend to be less productive (Wilkie et al. 2009b).

However, unless the canopy is heavily shaded there may not be a positive response to limb removal as macadamia flowers and sets fruit predominantly in areas of the canopy that receive less than 16% full day light (Olesen et al. 2011). Pruning trees that have large areas of the canopy already at or above this level is unlikely to increase yield. This may explain why even light pruning in young macadamia trees reduced yield (Olesen et al. 2011).

Where limb removal did increase yield, the increase in revenue was not greater than the cost of pruning and other related costs. In other crops, pruning results in economically important increases in fruit size that justify the pruning costs. Pruning in this study resulted in a small increase in nut weight but this did not affect revenue as NIS price is not determined by nut size. A large component of the cost of limb removal is the cost of chipping the removed limbs. There has been recent interest in the use of large forestry mulchers to reduce this cost and the overall cost of limb removal to A$2–A$8 per tree depending on tree size (G. Fleming, pers. comm.). This may make limb removal cost effective, especially when NIS price is high.

While limb removal to increase light penetration into the canopy may increase yield it has no lasting effect in increasing light transmission to the orchard floor required for ground-cover growth and orchard floor drying (Olesen et al. 2011). Removal of limbs to reduce tree height may maintain light to the orchard floor but it is not practical in tall trees. An alternative to the limb removal strategies studied here may be to remove large lower limbs to allow light penetration to the ground. In
mature orchards, these limbs tend to be unproductive and their removal may not result in a significant loss of fruiting wood.

Side-hedging effectively maintained the inter-row space but decreased yield by 12% on average over 7 years. Topping was a more practical method of reducing tree size than selective removal of limbs at the top of the canopy but it reduced yield substantially, by up to 50%. In Chapter 3, two hypotheses implicating an increase in fruit abscission as the cause of yield reduction following mechanical pruning were investigated. First, that it is due to the loss of photosynthetic canopy and second, that it is caused by competition for carbohydrates between the post-hedging shoot growth and fruit development. There is evidence for the former increasing fruit abscission in both deciduous and evergreen trees (Quinlan and Preston 1971; Berüter and Droz 1991, Mehouachi et al. 1995; Gómez-Cadenas et al. 2000) and for the latter increasing abscission in deciduous crops (Skene 1969; Quinlan and Preston 1971) but the competition between vegetative growth and reproductive growth has not been well defined for subtropical evergreen trees. The results in Chapter 3 clearly demonstrated an antagonism between shoot growth and fruit set, and patterns in stem carbohydrates supported the hypothesis that shoots and fruits compete for carbohydrates. The post-pruning shoot growth appeared to be the primary cause of increased fruit abscission with a smaller effect associated with the loss of canopy. The effect of pruning on fruit abscission and yield was supported in experiments on ‘A4’ (Chapters 3 and 4) ‘344’, ‘A38’ and ‘816’ (Chapter 4) and ‘849’ (Chapters 5 and 6). These cultivars covered the range of floral habits in terms of the proximity of racemes to the ends of the branches and hence to the post-pruning flush. This suggests that the pruning effect on carbohydrate supply and fruit retention extended over a significant distance.
The hypothesis was investigated that pruning trees at a time that avoided shoot growth during the premature fruit drop period may minimize the yield penalty. In apple, developing fruit appear less sensitive to a reduction in carbohydrate supply when it is imposed outside the premature fruit drop period (Berüter and Droz 1991). The results in Chapter 4 support this hypothesis. Pruning in September at anthesis was compared with pruning in October, November, December and June. October hedging stimulated new shoot growth during late fruit set. November and December pruning delayed the post-pruning flush until after fruit set, and June hedging allowed the post-pruning flush to fully expand before fruit set. Trees pruned in November and December had less fruit abscission and higher yield than trees pruned in September, and in some experiments had similar yields to unpruned control trees. October pruned trees had similar yields to trees pruned in September. June pruning gave mixed results. In one experiment June pruned trees had less fruit abscission and higher yields than trees pruned in September but in another experiment June pruning reduced flowering, and yields were similar to September pruned trees. It is possible that the latter result related to the low canopy density of the trees in that study. It seems unlikely to be a general effect as it is in contrast to a series of three experiments in which pruning in late May or early June did not reduce flowering (Wilkie et al. 2010). However, pruning in June may be riskier than pruning in November and December. Cool conditions may delay the start of the post-pruning flush to up to 9 weeks after pruning (Wilkie et al. 2009a) so that, in some seasons, flush development may still overlap with flowering and early fruit development.

The November and December pruning times are suited to an orchard with a regular light hedging program removing between 0.3 to 0.6 m of foliage. Hedging more severely may remove fruit at a time the tree is less able to compensate by
increasing set on the remaining branches. Light hedging is also preferred as a general strategy as severe hedging leaves behind a canopy with a shade induced loss of photosynthetic capacity that is not readily reversed by re-exposure of leaves to light (Huett 2004).

Trees pruned in November and December also tended to have shorter shoots in the post-pruning flush than trees pruned in September, which in turn, had shorter post-pruning flushes than trees pruned in June. This was consistent with the effect of decreasing shoot growth with increasing temperature demonstrated by Wilkie et al. (2009a) for non-bearing trees. There may also have been an effect of the developing crop on shoot length for the later pruning times in this study as the percentage reductions in shoot length from June to September pruning times (32% and 38%) were greater than the 14% reduction predicted by Wilkie et al. (2009a) using long-term weather data. The effect of pruning time on shoot length is of interest because shorter shoots are more likely to flower than long shoots (Wilkie et al. 2009b).

Despite the demonstrated effects of time of pruning on fruit set and yield, attempts to avoid the effect of topping on yield by topping ‘344’ trees in June and November (Chapter 2) were unsuccessful. In the case of the trees topped in June it appears that dry conditions delayed the development of the post-pruning flush until early November at which time it may have reduced fruit set. For the trees topped in November the reduction was similar to that for ‘A4’ trees topped in September in Chapter 3. The effects of topping may relate to the severity of pruning, with topping removing more canopy than the manual tip pruning or mechanical side-hedging used in experiments in Chapter 4. In citrus for example, severe pruning that was applied after the premature fruit drop period still reduced fruit number (Eissenstat and
Duncan, 1992. A bigger concern, however, was the much larger reduction in yield in the second year after topping in the November topped trees. It is possible that the synchrony of the post-topping flush was maintained and inhibited raceme production in winter (Wilkie et al. 2010) or even fruit set the following spring. The effect may also have been due to the dense, vigorous post-topping shoot growth shading the canopy below and limiting flower and fruit development (Myers 1993; Bussi et al. 2011).

Other strategies investigated to reduce the effect of pruning on fruit abscission and yield were either not effective or less effective than varying the time of pruning. The ethylene inhibitor AVG applied at six concentrations and two times did not increase final set or yield in pruned or unpruned trees (Chapter 5). The results suggested that post anthesis applications were more likely to be effective than pre anthesis applications but it is possible that the post anthesis application may have been too early to inhibit peak ethylene evolution. It is also possible ethylene is not the main control of abscission in macadamia. There is some support for a role of ABA in macadamia as ABA inhibitors not ethylene inhibitors increased the force required to remove fruit from macadamia explants (Salter et al. 2005b). In the broader context of understanding the control of fruit set in macadamia and prospects for improving yield, more detailed experiments involving responses of ethylene production and fruit abscission to ABA and ethylene inhibitors are required.

Girdling did reduce the effect of pruning on fruit abscission and yield (Chapter 6). Given the well known effect of girdling in increasing carbohydrate availability above the girdle this result is consistent with the hypothesis explored in Chapters 3 and 4 that pruning increases fruit abscission by reducing carbohydrates availability for
fruit growth. However, pruned and girdled trees still had 28% lower yield than unpruned and ungirdled trees. By comparison, in Chapter 4, when trees were pruned in November and December instead of September, pruned trees had similar or 14% lower yields than unpruned trees.

Girdling was also assessed in Chapter 6 for its potential to control shoot growth and tree size. Girdling reduced shoot growth in both pruned and unpruned trees but the effect appeared greater in unpruned trees. Over 3 years the increase in tree height in unpruned and girdled trees was half that of unpruned and ungirdled trees. Average yields over 3 years were similar but there was a trend for lower yields in later years for the girdled trees.

7.1 Future Directions

The prediction of yield decline in mature orchards presented in this thesis was an improvement on earlier work in which the prediction of yield decline relied on data from a single site. However, a reasonable criticism is that the prediction still relies on data from two cultivars from a few sites in one growing region and there is some uncertainty in extrapolating the results to the rest of the industry. Confidence around the prediction of yield decline in mature orchards is important to the industry for several reasons. First, it is critical for accurate crop forecasting to guide marketing strategies and industry investment. Second, it helps estimate the cost of the problem to inform prioritisation for research funding; and third, it will determine the economics of replanting. Use of grower yield data may allow further refinement of the prediction of yield change in mature orchards. Generally, growers have recorded whole farm yield, rather than individual block yields in which tree age, spacing and sometimes cultivar are uniform (Huett et al. 2002). However since 2001, some
growers in each of the growing regions have undertaken more detailed record keeping and analysis through their involvement with industry Best Practice Groups and the farm recording software MacMan (O’Hare et al. 2001). The possibility that these records could be used to refine the prediction of yield change presented in this thesis should be explored. It may be possible to develop predictions for different cultivars and growing regions.

The high degree of seasonal variation in macadamia orchards that makes prediction of yield change over the short term so challenging is an ongoing concern for the industry, especially with regard to the ability to accurately forecast production. The variation is often more apparent in older orchards, as it is for other tree crops (Monselise and Goldschmidt et al. 1982). It is due probably to climate effects initially, coupled with a tendency to biennial bearing (Wilkie 2009). These components are included in a macadamia crop forecasting model and while generally there has been good agreement between forecast and actual production, in some seasons the difference has been as high as 20% (Stephenson and Mayer 2009). This may be due to influences external to the crop production cycle such as rain during harvest and subsequent crop loss and low NIS prices providing a disincentive to harvest. It may also be due to discrete climatic events that are not detected by the forecast model which integrates weather data into ‘macadamia physiology periods’. It is also quite possible that effects of climate on tree physiology beyond our current understanding are responsible for discrepancies in some years. At the Centre for Tropical Horticulture, Alstonville, continuous yield records for trees up to 15 years old are available for four cultivars. There is scope to model both historical and future yield variation with weather data collected at the site to test hypotheses for climate effects on yield.
Limb removal increased yield in one of two trials in mature trees. While not cost-effective at current costs of limb removal, it may be a viable strategy as more efficient machinery becomes available. Further experiments in limb removal should be undertaken to check the reliability of this method in increasing yield in mature trees, especially across different cultivars. The effect on yield of removing lower limbs for light transmission for groundcover growth should also be investigated.

While removal of limbs at the top of the tree to reduce tree height was not practical for tall (> 9 m) trees it may be feasible if commenced when trees are smaller (5-6 m) and pruning can be done from the ground. In the trial on tall trees (Chapter 2) tree height was reduced by around 1.4 m with no significant reduction in yield. Three years later pruned trees were still 0.7 m shorter than control trees. The relatively slow recovery in tree height would enable at least a biennial limb removal program perhaps in rotation with side-hedging in early December to maintain the inter-row space. Application of PGRs to reduce vigour of the regrowth and the frequency required for repeat pruning could also be investigated.

Girdling may be useful as an additional tool to control tree height but further monitoring is required to check that tree health and yield are not negatively affected over the longer term.

Most of the experiments on the effects of time of pruning on fruit set and yield were conducted on small trees on which nearly all branches were pruned by hand-held pruners. In an orchard where trees are mechanically hedged, not every branch is pruned, especially those close to the top of the tree. As the negative effect of post-pruning shoot growth on fruit abscission appeared to be restricted to pruned branches (Chapter 3), the effect of pruning on tree yield, and therefore any benefit from varying
the timing of pruning, is likely to increase with the proportion of branches that are
pruned. One of the time of pruning experiments was conducted on mature ‘344’ and
‘A4’ trees using a commercial hedging machine to side-hedge trees (Chapter 4) but
the results were mixed, with time of pruning affecting yield of ‘344’ trees but not
‘A4’ trees. This may have been due to low fruit set in the ‘A4’ trees in that season.
The effects of time of pruning on yield reported in this thesis need to be validated in
mature orchards pruned with mechanical hedgers over several seasons.

Pruning time affected shoot length and this may have implications for
flowering in subsequent seasons as Wilkie et al. (2009b) demonstrated that short
shoots are more likely to flower than long shoots. However, further work is required
to test if the magnitude of differences in shoot length between pruning times
significantly affects the probability of raceme production. Other strategies to increase
the proportion of shoot stems in the canopy should also be investigated. This may
include branch tipping in young trees and/or the use of PGRs.

Timing topping to avoid post-pruning shoot growth during fruit set did not
appear to mitigate the negative effect on yield. This may relate to the severity of
pruning and investigations into a lighter topping regime aimed at maintaining rather
than reducing tree height should be pursued. The effect may also relate to a persistent
synchrony in the post–topping flush development and/or increased shading in the
canopy below the post-topping shoot growth that affects raceme and fruit
development in subsequent seasons. More detailed investigations into the behaviour
of the post-topping flush and interactions with flowering and fruit set are required to
improve outcomes for topping. This could include experiments with the growth
regulator uniconazole. Uniconazole delayed bud release in macadamia following
pruning (Wilkie et al. 2010) possibly disrupting the synchrony of the post pruning flush and decreasing its capacity to inhibit raceme production and/or fruit set. The vigour of the post-pruning flush was also reduced by uniconazole (Wilkie et al. 2010) which may diminish shade effects on flower and fruit development.

Significant advances in canopy management in other crops, especially apple, have been possible due to the availability of dwarfing rootstocks, and selection of these rootstocks for macadamia should be a priority for future research. Precocity is a feature of dwarfing rootstocks (Tukey 1964) and, in general, the more dwarfing the rootstock the greater the precocity (Palmer 1997). This association could be used in early screening for dwarfing rootstocks. Precocity also has benefits for the economics of orchard development, including orchard replanting.
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Publications and presentations

**Scientific Journals**


**Technical Reports**


**Presentations**


Australian Macadamia Society Researchers 2 T Task Force Meeting 2012, Nambour. Yield decline in mature orchards (a joint presentation with Jeremy Bright and Mark Hickey, Extension Horticulturists, NSW Department of Primary Industries).

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**Posters**
