Lychee, Longan and Rambutan
Optimising Canopy Management

A report for the Rural Industries Research
and Development Corporation

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Foreword

Lychee (Litchi chinensis Sonn.), longan (Dimocarpus longan Lour.) and rambutan (Nephelium lappaceum L.) are popular exotic fruit native to Asia. Australia produces about 5000 tonnes of these crops annually, returning about $22 million. Lychee and longan are subtropical, but their distribution also extends into the tropics at elevation. Major production areas are in northern, central and southern Queensland. Rambutan, however, is strictly tropical, with 85% of production in northern Queensland and the balance in the Northern Territory. On a per hectare basis, the rate of return for these crops compares more than favourably with alternatives such as macadamia, stonefruit and mango. Lychee is very popular, with developing export markets in South-East Asia, Europe and the Pacific Islands.

Left unchecked, all these crops grow into large trees that are difficult to spray, harvest and net. Up to 60% of the lychee crop is lost each year to birds, bats and fruit-piercing moths. Exclusion netting is an effective way to control these pests, but is most practical with small trees. Small trees can also be closely planted and provide greater returns in the early life of an orchard. The other major problem with lychee and to a lesser extent longan is irregular flowering and poor fruit retention.

This report details methods of canopy management to increase the profitability of lychee orchards in northern Australia, and indicates areas for future experimentation. It also suggests further areas of research in longan and rambutan.

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General Summary

We have successfully demonstrated that it is possible to prune lychee orchards to maintain tree size and promote flowering and cropping. Regular flowering and cropping in lychee is a major problem throughout the world. Lychees grow by recurrent terminal flushes. Previous investigations in glasshouses showed the rate and duration of shoot growth was strongly related to temperature, and that flowers are initiated on these terminal flushes. We found that induction occurred when small buds, a few millimetres long, grew during cool inductive conditions. These observations provided a potential opportunity to control flowering on-farm using pruning to synchronise growth during inductive conditions. This has the added benefit of controlling canopy size.

These principles were used to develop a model of flushing against radiation and temperature which was used to predict the optimum time of pruning along the eastern coastline of Australia. This model was then validated in commercial orchards. The model showed that flushing is slower in the southern cooler cloudier areas (eg. Ballina in northern New South Wales) and that pruning must be carried much earlier than in the northern warmer sunnier locations (eg. Mareeba in northern Queensland). Should a tree fail to flower in autumn, a second opportunity can be provided using ethephon as a selective desiccant to remove young growth and promote the initiation of a new flush.

Trees pruned at the optimum time were shown to have similar yields on a canopy surface area basis as productive non-pruned control trees. This is a significant development for the Australian lychee industry. Previous research suggested that yields were often reduced after pruning. However, these experiments were not based on an understanding of the mechanism of shoot growth and flowering in this species. Smaller trees after pruning are more economic to harvest, spray and net for birds and bats, and can be planted at close spacings. Gross returns for pruned, netted and closely-planted orchards were more than double those of traditional orchards.

Longan behaves in a similar fashion to lychee, with similar climatic requirements for flushing and flowering. As with lychee, experiments showed that the interval between flushes was much longer in cool cloudy environments than in warm sunny localities. Further experiments are required to test these principles in commercial orchards, and to determine the optimum time of pruning in different districts.

Rambutans did not respond in a predictable fashion to pruning in the Northern Territory. There was quite a large variation in the response to different treatments from year to year. In general, pruning delayed harvest with tipping resulting in more synchronised crops. It is difficult to extrapolate these results to other growing areas such as northern Queensland. We need to understand the mechanism of flowering before we can develop effective tree management strategies for this species. Large-scale field experiments such as fertilizer or pruning trials which aim to manipulate cropping may be more difficult to interpret without this information.

In some districts, irregular flowering and poor fruit retention continue to affect lychee orchards. There are also production issues in longan and rambutan. Suggestions for future research and development in these crops are indicated below.

The key factor limiting floral induction in lychee is lack of cool temperatures during winter. This is especially important in northern coastal regions, but also affects the Atherton Tableland some years. Yields are more consistent in subtropical localities with days below 20°C during winter. The chemical signal for flowering is thought to be produced in the leaves. The use of evaporative cooling by wetting leaves has been shown to enhance the chilling response in other subtropical crops such as kiwifruit, but has not been tested in lychee. Small scale trials indicate reductions of 3°C-5°C are readily achieved. This approach has the potential to extend growing areas, extend the cropping period and further refine the control of flowering.
Internationally, girdling and to a lesser extent growth regulators such as auxins have been used to improve fruit retention and yield of lychee. Small scale trials in Australia have confirmed yield benefits from girdling both prior to flowering and after fruit set. These need to be confirmed on a commercial scale and set into the current management system.

Yield in lychee is related to light interception and canopy structure. Investigations are needed to optimise light distribution and canopy photosynthesis through pruning. This approach may provide greater returns than girdling or application of growth regulators.

Biennial bearing and failure to flower affect longan orchards throughout Australia. These are largely explained by the late cropping and slower flush cycle compared with lychee. Alternative strategies for pruning, techniques for forcing bud growth, and crop removal are needed.

The different flowering and cropping patterns of rambutan in the Northern Territory and Far North Queensland indicate that environmental conditions regulate flowering and fruit production in this crop. Rambutans quickly become difficult to manage without pruning. There is an obvious need to develop further pruning strategies, especially in the wet tropics. However, more basic research on floral initiation should be initiated at the same time. Glasshouse trials are needed to indicate the critical genetic and environmental factors affecting production.
Executive Summary

Left unchecked, lychee (*Litchi chinensis* Sonn.), longan (*Dimocarpus longan* Lour.) and rambutan (*Nephelium lappaceum* L.) from the family Sapindaceae grow into large trees that are difficult to spray, harvest and net. Up to 60% of the lychee crop is lost each year to birds, bats and fruit-piercing moths. Exclusion netting is an effective way to control these pests, but is most practical with small trees. Small trees can also be closely planted and provide greater returns in the early life of an orchard. The other major problem with lychee and, to a lesser extent, longan is irregular flowering and poor fruit retention. The objective of the project was to develop pruning strategies to stabilise production and reduce tree size, with the main focus on lychee, and less emphasis on longan and rambutan.

Activities in lychee

**Effects of pruning on flushing and flowering**

Models of lychee flush development were developed from experiments at Alstonville in northern New South Wales (lat. 29°S) and Bundaberg in southern Queensland (lat. 25°S). Trees were pruned to remove the latest flush on all branches. The pruning caused a change in the phase of the flushing cycle relative to non-pruned trees, affecting the timing of flowering at one site, and the extent of flowering at the other.

**Commercial Implications.** Experiments have shown that the flushing cycle of lychee trees in the field can be altered by strategic pruning. This allows growers to regulate flowering and cropping and to keep their trees small. Previous work suggested that pruning reduces cropping in lychee. However, this research was not based on an adequate understanding of growth and flowering in lychee. Significant advances in the management of this crop have been made.

**Model of flush development**

The recurrent flushing patterns of well-watered, well-fertilised Kwai May Pink lychee trees were studied using a field-based pruning trial.

The vegetative cycling rate (the reciprocal of the time between the emergence of successive flushes) was strongly related to the daily irradiation-temperature product. A model of this relationship was applied to long-term weather records from along Australia’s north-eastern seaboard, to illustrate the latitudinal variation in flush development. For example, for a new flush to commence on the day of the winter solstice in the median year, the previous vegetative flush would need to have started in early March in northern New South Wales and in late March in north Queensland.

Long-term weather records were also used to estimate the latitudinal variation in the annual number of days of florally inductive weather (mean daily temperatures <20°C) and showed that in coastal northern Queensland, there may be years in which inductive weather conditions do not occur.

**Commercial Implications.** A model was been developed to assist lychee growers to prune their trees at the most appropriate time after harvest. The optimum time of pruning varies from northern Queensland to northern New South Wales. The model allows for one or two growth flushes before winter in warmer areas and one flush in cooler areas. In any one location, the optimum time of pruning does not appear to vary dramatically across different cultivars. The model is a significance advance as it takes into account the effect of weather on the flushing rate of lychee in different localities. Previous research did not provide recommendation for individual growing areas.

**Assessment of growth model**
Pruning trials were conducted on Kwai May Pink lychee in two commercial growing areas of Queensland to assess the model of vegetative flush development.

For the 1998 staggered pruning trial near Mareeba where the trees were pruned every 10 days, the sinusoidal time-courses of flowering and yield against pruning date had periods of 62 days, a minimum on 11 February and a maximum on 14 March, in accord with the expectations of the model developed at Alstonville. These results translate into pruning dates of early March or early January, giving one or two vegetative flushes before winter, respectively. The results from the 1995-97 Mareeba trials were also consistent: the prediction from the model was for \( \approx 50\% \) floral success, while in practise, flowering for the three years was good, then fair, then negligible, relative to the controls.

The pruning times from the model for trees growing near Bundaberg were: mid-February for a guaranteed single flush before winter; and early March for the median of one flush before winter. Poor flowering was expected from trees pruned from late January to early February and from mid- to late March. Those trees pruned in early February and in late March in 1997 did, as expected, flower weakly and crop poorly. Those trees pruned in either late February or early March from 1995-97 all flowered and cropped as well as the control trees, which was a somewhat better performance than predicted.

### Commercial Implications
The lychee growth model was shown to give a good estimate of flushing patterns and flowering when the trees were pruned at different times in the two locations. It can thus be used as a reliable guide for calculating the best time for pruning in the different lychee growing areas in northern Australia.

### Grower pruning trials
Trees in commercial orchards were pruned at various times from late January to late March in 1998 at 17 sites. Overall, flowering was generally best with pruning in early February in northern New South Wales, from mid-February to early March in southern Queensland, and from early to mid-March in northern Queensland.

### Commercial Implications
Canopy management was evaluated by commercial lychee growers across eastern Australia. Trees were pruned at various times after harvest and their growth and performance assessed. This strategy to get growers involved has worked very well, and has heightened the value of canopy management to industry.

### Remedial measures
We were interested in remedial treatments to control late autumn flushes which generally do not flower. Trees with young red flushes in winter growing at Mareeba, Bundaberg and Childers were pruned or sprayed with ethephon (as 1 to 3 litre of Ethrel plus 5 kg urea per 1000 litre) in May and June, and subsequent flush development, flowering and yield determined.

Control trees with red flushes in May and June generally flowered poorly when rated in early August. The best flowering occurred with trees lightly pruned in May or sprayed with ethephon in June. These experiments demonstrate the value of remedial measures if leaf flushes develop in winter.

### Commercial Implications
The model of lychee flush development can be used to estimate the optimum date for pruning in different districts. However, in warmer than average years, the trees may produce a late autumn leaf flush which will not flower. A light pruning in winter or application of ethephon can selectively remove these flushes and restore cropping. These treatments build on
research which developed pruning strategies after harvest to control tree size, and improve the reliability of fruiting in commercial orchards.

Estimating leaf area in field-grown trees

Productivity in tree crops, such as lychee, is driven by the amount of light intercepted by the canopy. In leaf stripping experiments, the DEMON instrument (Li-Cor) estimated 68% of actual leaf area (explained variance 89%), compared with the LAI-2000 (CSIRO) which estimated 11% of actual leaf area (explained variance 68%).

Commercial Implications. A non-destructive method was developed to estimate leaf area in lychee trees. This method can be used in future research to examine the relationship between yield and leaf area in lychee, under different pruning regimes. Direct measurements of leaf area in tree crops are very expensive.

Relationship between yield and leaf area

Changes in lychee yield and leaf area production were studied in trees ranging from six to nine years of age, with at least 0.5 m between adjacent trees. Canopy surface area per tree varied from 24 to 53 m²; total number of leaves from 2700 to 9200; and total leaf area from 11 to 40 m². Relative leaf area index, that is, the ratio of leaf area to canopy surface area, varied from 0.48 to 0.83 and was essentially independent of tree size. Relative yields were 19.2 ± 1.6 of fruit per m² of canopy surface area, or 30.7 ± 2.6 of fruit per m² of leaf area across the various trees, and not correlated with canopy surface area. In other words, fruit production was simply dependent on the total bearing surface of the trees, so that large trees were not more efficient (fruit per unit leaf area) in producing fruit than small trees.

Commercial Implications. Fruit production was shown to be dependent on the total bearing surface of the trees, so that large trees were not more efficient in producing fruit than small trees. These results indicate that small trees planted at close spacings will be just as productive as large trees planted at wide spacings. They will also make efficient use of land in the first few years after planting, and will be easier to harvest, spray and net. Overall returns to growers will be greater with this system.

Activities in longan and rambutan

The recurrent flushing patterns of well-watered, well-fertilised Kohala and Chompoo longan trees were studied at Nambour in southern Queensland (lat. 27°S) using a field-based pruning trial. The intervals between successive flushes was strongly related to the irradiation and temperature, with the explained variance of the various regressions ranging from 75 to 83%. The flushing rate (the reciprocal of the time between the emergence of successive flushes) was also strongly related to daily irradiation*temperature, with the explained variance of the regressions ranging from 76 to 88%. These results were broadly consistent with those for lychee.

Average yields of Jitlee and R167 rambutan pruned in February in Darwin were 24% lower than the controls, and those of the plots pruned in February and June, 37% lower. These yields were equivalent to 5.6 to 15.8 t ha⁻¹ at a density of 200 trees ha⁻¹.

Commercial Implications. A model was developed to predict the flushing patterns of longan in different environments. With further work, this model could be used to predict the optimum time of pruning in different districts. Preliminary work in northern Queensland, suggests that longan trees
should be pruned as soon as possible after harvest. No specific recommendations can be give for other districts.

Rambutan trees were pruned in the Northern Territory and their performance assessed over three years. Pruning after harvest in February was more reliable than tipping in winter. The commercial benefits of pruning in this and other environments are yet to be determined.

**Industry extension**

Research findings have been reported at 14 field days in Darwin, Mareeba, Bundaberg, Nambour and Ballina. There have also been presentations at the National Lychee Conferences in 1996 (Yeppoon) and 1999 (Sunshine Coast), and over 20 articles published in *Living Lychee* and other journals. A colour brochure highlighting the main results of the project was released at the National Lychee Conference in 1999. Commercial growers have also evaluated pruning on their farms.

**Outcomes**

The project has developed pruning strategies for the Australian lychee industry. The optimal time for pruning varies with latitude from Cairns and Mareeba in northern Queensland, to Bundaberg and Nambour in southern Queensland, and Byron Bay in northern New South Wales, but is similar across cultivars in a given locality. In warm northern areas, the option exists for pruning to achieve one or two shoot flushes before winter flowering, while in southern cooler areas the best approach is to prune for one flush before winter. As trees are smaller after pruning (canopy surface area reduced by 30% compared with non-pruned trees), harvest costs are reduced, and spraying and netting are easier. Trees can also be more closely spaced. High density plantings maximize the use of land and should provide greater returns in the early life of an orchard.

No commercial recommendations have been developed for longan and rambutan. Options for future longan research include pruning trees as soon as possible after harvest, or pruning a proportion of the tree at flowering in an effort to reduce biennial bearing. The role of ethephon in controlling winter flushes also warrants further research. The factors controlling flowering in rambutan are not well understood. Results from Darwin showed that yields per tree were 24% lower after structural pruning, but on a much smaller canopy. The application of these results to other growing areas is yet to be determined.
Setting the Scene

Lychee (*Litchi chinensis* Sonn.), longan (*Dimocarpus longan* Lour.) and rambutan (*Nephelium lappaceum* L.) are related tropical trees in the family Sapindaceae that produce fruit containing an edible aril. Lychee and longan are pantropical and produce a single crop annually, while rambutan is strictly tropical and may fruit twice a year. The major problem with lychee and, to a lesser extent, longan is irregular flowering and poor fruit retention (Menzel and McConchie 1998; Lim and Diczbalis 1998).

In the past, yields have been low in all these crops due to inappropriate cultivars and poor management. Cultivars that produce premium quality fruit have been introduced and evaluated. Improved management needs to be developed. Strategic pruning provides a means of regulating flowering in lychee, while synchronising the crop and allowing canopy manipulation. Lowering and opening the canopy of lychee reduces netting and harvesting costs and facilitates pest control. To increase profitability, improved management techniques need to be developed and adapted to the premium cultivars in the tropical and subtropical Australian production centres. This will improve the commercial viability of these crops.

Growth in these species occurs as a series of flushes during summer and autumn followed by flowering in the terminal branches. In lychee, flowering occurs after a period of low temperatures (Menzel *et al.* 1989; Menzel and Simpson 1995), with or without assistance from water deficits (Menzel 1983). A vegetative flush prior to the onset of cool weather is detrimental to flower formation (Menzel 1983), but conditions during floral induction must be suitable for active growth (Batten and McConchie, 1995). If temperatures below 20°C occur during bud break, flower panicles will be induced. However, if warm weather persists at this time, only vegetative shoots will be produced. Flowering can be manipulated by pruning the trees at the appropriate time so that buds develop when induction is likely to occur.

Extensive cultivar assessment and research in basic cultural practices have been performed in the Northern Territory and North Queensland for rambutan and longan (Menzel and McConchie 1998; Lim and Diczbalis 1998). However, development of high-density planting and intensive management, as proposed for lychee, would further increase profitability of these crops.

In South East Asia, approximately 800,000 t of rambutan, 500,000 t of longan and 600,000 t of lychee are produced annually. Between 20,000 t of rambutan and 50,000 t of lychee are traded as fresh fruit during the northern hemisphere season. In 1996, Australia produced 3,000 t of lychee returning $15 million. On a hectare basis this rate of return more than favourably compares with alternative crops such as macadamia, stonefruit and mangoes. New marketing groups have been formed in north, central and southern Queensland and northern New South Wales, with active quality assurance schemes that have increased returns to growers and raised the quality of the marketed fruit. These groups have approximately 120 members, representing 30% of the industry. In a good season, these marketing groups can market approximately 500 t of lychee returning $2.5 million.

Data collected in 1995 showed that up to 60% of the lychee crop is lost each year to birds, bats and fruit piercing moth. The only effective way to control these pests is with exclusion netting. Some preliminary netting trials have been very effective and have greatly increased profitability. One grower increased returns by $105,000 for a $12,000 outlay on nets. Effective canopy management strategies are required before netting becomes economic for most growers. If netting was adopted industry wide, the current value of the industry would immediately more than double to $30 million.

Australia has a geographic advantage to supply off-season fruit to Asian economies where these crops are well known and shipments have been competitive with returns on local markets. Over the past few seasons, the marketing groups have also successfully opened sales in UK, Canada and the Pacific Islands. About 30% of the total crop was exported in 1996.
In Australia, there are also 220 ha of rambutan producing 800 t of fruit for an estimated return of $5.5 million. Many of these plantings of rambutan are still immature. Eighty-five percent of this production is in northern Queensland and 15% in the Northern Territory. Commercial longan plantings cover less than 100 ha. Total production in 1997 was about 150 t worth $1.5 million. Most of the orchards are in northern Queensland, with much of the expansion expected to occur on the Atherton Tableland.

Left unchecked, all these crops grow into large trees that are difficult to spray, harvest and net. Exclusion nets are an effective way to control the important bird, bat and piercing moth pests in these crops, but is most practical with small trees. Small trees can be closely planted and should provide greater returns in the early life of an orchard.

The effects of pruning on flowering and yield of lychee trees have been studied in Florida (Young 1977), Taiwan (Yen and Tien 1985), Israel (Goren 1990) and Australia (Menzel et al. 1996). Trees were pruned in summer, autumn or winter, but responses were mixed. None of these authors pruned their trees with the idea of achieving a single or double flush before winter. There have been no studies published on pruning of longan and rambutan.

This project was developed in close consultation with industry through a series of meetings at which an industry strategic plan was developed. This plan identified the area of canopy management as the top research priority. Groups consulted include the Australian Lychee Growers’ Association, the Lychee Subcommittee of Queensland Fruit and Vegetable Growers, regional lychee associations, the lychee marketing groups, and the Rambutan Growers’ Association. They fully supported the project and its objectives.

**Project Objectives**

*Period from July 1994-June 1997*

To ensure reliable and profitable yields are obtained by the lychee, longan and rambutan industries by building on the advancement made in previous research and by developing canopy and orchard management design to regulate and improve yields. This will be achieved by:

1. Developing pruning strategies to synchronise and promote flowering, leading to increased and regular yields.

2. Investigating the use of leaf area indices as a means of standardising pruning treatments by quantifying light interception within canopies.

3. Developing high density plantings of grafted plants as means of providing earlier and increased yields per hectare during early years of orchard establishment.

4. Developing high density orchard management systems for early production and high yields per hectare to maximise profitability.

5. Working closely with industry to assist the rapid adoption of best crop management systems.

*Period from July 1997-June 1999*

To improve profitability in the lychee, longan and rambutan industries by:
1. Developing pruning strategies to synchronise and promote flowering, leading to increased and regular yields.

2. Developing protocols for the application of ethephon sprays to control winter flushes which prevent flowering in lychee and longan.

3. Evaluating high density plantings as means of providing earlier and increased yields per hectare during early years of orchard establishment.

4. Developing high density orchard management systems for early production and profitability.

5. Working closely with industry to assist the rapid adoption of best crop management systems.

References


Effects of Pruning on the Flushing Cycles and Flowering of Lychee

Summary

Models of lychee flush development were developed from experiments at Alstonville in northern New South Wales (lat. 29oS) and Bundaberg in southern Queensland (lat. 25oS). Trees that bore a red-green flush were pruned in such a way as to remove the latest flush on all branches. The pruning caused a change in the phase of the flushing cycle relative to non-pruned trees. The change in phase affected the timing of flowering at one site, and the extent of flowering at the other site.

Two simple models were used to describe flush development, the Richards logistic function and a modified sine function. The Richards function generally fitted the data slightly better than the sine function, but gave poorer estimates of flush lengths during early flush development. The variation in the maximum elongation rates of the vegetative flushes was largely a function of irradiation. The maximum elongation rates of the floral flushes seemed to be similarly dependent on irradiation, however irradiation and temperature were correlated, and the influences of these two factors on floral flush development could not be separated. Floral induction generally occurred when air temperatures were below 20°C.

Commercial Implications. Experiments have shown that the flushing cycle of lychee trees in the field can be altered by strategic pruning. This allows growers to manipulate their trees to flower and crop. There is also the added benefit that pruning can control the size of the trees. Smaller trees are easier to harvest, spray and net, and can be planted at close spacings. Previous work suggested that pruning reduces cropping in lychee. However, this research was not based on an adequate understanding of growth and flowering in lychee. Significant advances in the management of this crop have been made.

Introduction

Lychee is an evergreen tree that grows to approximately 20 m (Menzel et al. 1996). It is native to the subtropical rainforests of South-East Asia, especially those of southern China and northern Vietnam, but has a much wider distribution owing to the popularity of its fruit. As a horticultural crop, however, it flowers and fruits irregularly.

The branches of lychee grow by recurrent flushing (Batten and Lahav 1994). Several leaves and internodes emerge in quick succession, after which there is a lag of growth, followed by a new series of leaves and internodes, and so on. The lag phase seems to be an intrinsic part of shoot development, possibly involving a signal from the immature leaves of the latest flush that suppresses further bud development.

Mean daily temperatures below 20°C are needed for flowering in lychee (Menzel and Simpson 1995), but the number of days of such temperatures required for effective induction is not known. Part of the reason for this uncertainty is that the inductive stage of development has only recently been recognised. Batten and McConchie (1995) showed that panicles could be initiated if early flush development corresponded with inductive weather, even if no inductive weather occurred during the lag phase. They also provided some evidence that warm temperatures during early flush development could override cool weather during the lag phase. Salathiel plants were initially grown outside, moved to a glasshouse at 25°C, and then transferred back outside to a northern New South Wales winter with a mean daily temperatures of 14.3°C. None of the plants with buds longer than 4 mm in the glasshouse flowered. Thus, the determination of a flush as either vegetative or floral seems to depend
largely on the weather conditions during early flush development.

It follows that irregular flowering is related to a lack of synchrony between early flush development and inductive weather conditions. If so, the solution is to find an effective means of changing the phase of flushing. Pruning is a very effective method of stimulating new shoot growth in lychee. Here we report on the effectiveness of pruning to alter the pattern of flushing and flowering of lychee trees in eastern Australia.

Lychee is grown from northern New South Wales to northern Queensland, and the ultimate purpose of our current project is to estimate optimum pruning times across this range of environments. Estimates of the maximum elongation rates of the flushes were related to irradiation and temperature, as a preliminary guide to the kinetics of flush development. These relationships were estimated from curves fitted to the variations of flush length over time. Two types of curves were fitted. The first of these was the Richards function, one of the family of logistic curves routinely used to describe deterministic growth in plants (Dennett et al. 1978; Batten and Lahav 1994). The second was a modified sine function, not used previously to describe plant growth.

The curves were also used to estimate the times at which the new flushes were undergoing floral/vegetative determination, so that the first field estimates of inductive/non-inductive weather could be made. To analyse the process of induction further, leaf-stripping of trees was used to examine the role of mature leaves in the transduction of environmental cues. Leaves are a major source of the floral signal in mango (Nunez-Elisea and Davenport 1992), and the leaves need to be at least seven weeks old to be effective (Nunez-Elisea and Davenport 1995). Given the great similarities in the floral biologies of lychee and mango (Batten and McConchie 1995), those trees stripped of their leaves were not expected to flower.

Materials and Methods

Pruning of trees in commercial orchards

On March 2, 1995, ten trees of the lychee cultivar Kwai May Pink growing near Ballina in northern New South Wales (29°S 153°E) were chosen for study. The trees were ten-year-old marcots, 5 m high, growing on a deep krasnozem soil. Their leaf nutrient concentrations were within industry standards, while the water input from rainfall and irrigation was super-sufficient with respect to industry standards (Greer 1995). Each tree had an even coverage of fully extended red-green flush. Five of the trees were pruned with a prune-trimmer, removing approximately 40 cm from every branch terminal. The other five trees were non-pruned controls. Eight branches were tagged on each tree, one metre from the top, at the edge of the canopy.

On March 8, 1995, the experiment was replicated near Bundaberg in southern Queensland (25°S 152°E) with only the following differences: the trees were eight-year-old marcots, four metres high, growing on a shallow sandy loam.

At approximately fortnightly intervals, records were made for the most recent flush on each tagged branch of its length, its status as either vegetative or floral, and, if floral, the number of branches >10 mm long. Sheltered automatic weather stations (Minimisers, Northern Rivers Industrial Electronics, Lismore) placed in largely open paddocks to the north of the experiments, measured mean hourly irradiation (400-1100 nm) and air temperature. At harvest, yields were measured as either fruit number or fresh fruit weight.

Leaf stripping

Five trees of Kwai May Pink were manually defoliated at the Tropical Fruit Research Station in
Alstonville (29°S 153°E) in northern New South Wales from April 16-19, 1996. The trees were ten-year-old marcots, 8 m high. For each stripped tree, the number of new shoots to emerge by October 1996 was recorded, and each shoot scored as either vegetative or floral. Five adjacent non-stripped trees were monitored in the same way. The twenty three remaining non-stripped Kwai May Pink trees within the orchard were more simply scored, at the same time as the other trees, as either flowering or not.

Analyses

Two types of curves were fitted to the flush growth data by non-linear regression. The first was a variation of the Richards logistic function:

\[ y = y_{\text{max}} \times \left[ \frac{(1 + e^{-(j-x)})^v - (1+e^{x})^v}{1 - (1 + e^{x})^{-v}} \right] \]

where,  
\( y \) = length of the flush
\( y_{\text{max}} \) = maximum length of the flush
\( x \) = time from flush commencement
\( v \) and \( j \) = form parameters related to the slope and symmetry of the curve

The second was a sine function:

\[ y = y_{\text{max}} \times \left( \frac{(\text{sine}(\pi \times r \times x - (\pi/2)) + 1)}{2} \right)^{1/t} \]

where, \( r \) and \( t \) = form parameters related to the slope and symmetry of the curve

The date of the visit prior to the day on which the first visible signs of new flush growth were observed was nominated as the time of flush commencement. The maximum flush lengths were fixed at the measured values. Thus only two parameters were estimated for each function. The sine function was further constrained by having the final day for shoot extension no later than the day on which the maximum flush length was measured for the first time. Characteristics of the functions are given in the Appendix to this chapter.

All regressions for the study were fitted using the Marquardt-Levenberg algorithm in SigmaStat (Jandel Corporation). Only significant regressions were incorporated into graphs. All the fitted curve presented satisfied \((P_{0.05})\) conditions of normality and constant variance.

Means were compared using the pair-wise t-test. Medians were compared using the sign test.

Solar declination and radiation transmission

Solar declination (\( \delta \)) was calculated using Spencer’s equation (Iqbal 1983). Radiation transmission is the ratio of actual incident radiation to that expected from the linear regression of daily irradiation (I) against solar declination for blue sky conditions. The regressions for the sites near Ballina and Bundaberg were, respectively, \( I = 23.1 + 0.43 \times \delta \) (\( r^2 = 0.99 \); - 23.5° < \( \delta \) < 16.1°) and \( I = 23.2 + 0.40 \times \delta \) (\( r^2 = 0.99 \); - 23.5° < \( \delta \) < 1.4°) for I in MJ m\(^{-2}\) d\(^{-1}\). Radiation transmission is used in two ways: firstly, to describe the variance in radiation load; secondly, as an index of cloudiness.

Results

Effects of pruning on phenology and yield

At both sites, the tagged branches of the pruned trees commenced a new flush within a fortnight. The
controls flushed later than the pruned trees, but before the pruned trees had started to flush for a second time. Thus, pruning changed the phase of flushing. The point is illustrated with respect to the longest flush to develop on each tree during each flushing episode (Figure 1).

Near Ballina, the consecutive flushes of the pruned trees began in March and July/August. The first flush was vegetative, the second largely so. One of the 5 trees bore 5 fruit, and the other 4 trees bore no fruit at all. The autumn flushes of the controls flowered in early October (Figure 1). No further panicle elongation occurred after the visit on which the apical flower was recorded as open. By February 1996, there was a modest crop of 828 ± 120 (s.e.) fruit per tree.

Near Bundaberg, the consecutive flushes of the pruned trees began in March and July/August, with the first, vegetative and the second, floral (Figure 1). The trees flowered in October. The yield for the pruned trees in January 1996 was 15.8 ± 3.4 kg per tree. For the controls, a floral flush was initiated in May, and the trees flowered in mid-September (Figure 1). The yield in January 1996 was 19.5 ± 3.4 kg per tree. Although the pruned trees were approximately 8 weeks behind the controls in the initiation of their floral flush, they were only three weeks behind in flowering, and only one week behind at harvest. As with the trees near Ballina, no further panicle elongation occurred after the visit on which the apical flower was recorded as open. The panicles were of similar length for the two treatments, but those of the pruned trees were less branched (Table 1). The difference between yields was not significant (t-test, \( P < 0.05 \)).

Table 1. Numbers of primary, secondary and tertiary branches (>10 mm long) per panicle. Results presented as means and standard errors, N = 5. Identical superscripts within columns represent non-significant differences (t-tests, \( P > 0.05 \)). The abbreviation n.a. stands for not applicable.

<table>
<thead>
<tr>
<th>Branches</th>
<th>Ballina</th>
<th>Bundaberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>9.8 ± 1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>11.2 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pruned</td>
<td>n.a.</td>
<td>7.4 ± 0.6&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>2&lt;sup&gt;o&lt;/sup&gt; branches</td>
<td>15 ± 2.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>23.2 ± 2.9&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>3&lt;sup&gt;o&lt;/sup&gt; branches</td>
<td>1.0 ± 0.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.0 ± 0.6&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Maximum elongation rates

To examine the dependency of the maximum stem elongation rates on irradiation and temperature, only the longest flush to develop on each tree during each flushing episode was considered. The constraint was made primarily to restrict the analysis to those regressions where an estimate of the maximum rate could most confidently be made, since the longer flushes tended to elongate over a longer period, and so had more measurements of intermediate lengths taken. Both the Richards and sine functions were fitted to the data for individual branches. As a guide to the general goodness of fit of the two functions, the sum of squares about the points of intermediate flush development (i.e. excluding points representing full flush length) were tallied. For the thirty flushes, the sum of squares about the Richards curves was smaller than that about the sine curves (4397 versus 6534 mm\(^2\)), but both were very small compared with the tally of the total sum of squares (557741 mm\(^2\)). In other words, the fitted Richards and sine curves represented the data well.

Maximum elongation rates, and the days on which these occurred, were estimated from the fitted curves (Appendix). To relate the rates to temperature and irradiation, the day on which each flush reached its maximum rate was used as the mid-point of an eleven-day block, over which temperature
and irradiation were averaged. By using this block size, much of the day to day variation in temperature and irradiation was smoothed out (Figure 2), which was desirable, given the uncertainty surrounding the estimates of the days on which the maximum elongation rates occurred (Figure 3).

The maximum elongation rates calculated from the Richards function were higher than those from the sine function (Figures 4 and 5). The difference is perhaps an indication of the greater flexibility of the Richards function, though it is not clear which function gave the more reliable estimates.

Irradiation and temperature were poorly correlated (r = -0.14 for both the Richards and sine function estimates, n = 15, P>0.05) for the times at which the maximum elongation rates of the vegetative flushes occurred, and were treated as independent. With respect to irradiation, the maximum vegetative elongation rates, whether calculated from the Richards or sine functions, peaked at 15.9 MJ m⁻² d⁻¹ (Figure 4A). There was no obvious rate-temperature relationship for either function (Figure 4B).

For the times at which the maximum elongation rates of the floral flushes occurred, irradiation was positively correlated with temperature (r = 0.81 and 0.78 for the Richards and sine function estimates, respectively, n = 15, P<0.05), so the two factors could not be regarded as independent. Hence, no attempt was made to fit curves to the rate-irradiation (Figure 5A) or the rate-temperature (Figure 5B) plots.

To account for the irradiation-temperature dependency, the maximum floral elongation rates were standardised to constant temperature, by dividing the rates by temperature. There are four lines of evidence to justify the mathematics of such a standardisation. Firstly, Batten and Lahav (1994) found that the rate of leaf expansion in lychee increased with increasing temperature across a temperature range similar to our data. Secondly, Olesen et al. (2000) found an 89% increase in the maximum elongation rates of vegetative flushes over the range 19° to 24°C. Thirdly, the non-significant regressions of the maximum elongation rates of the vegetative flushes against temperature for the data presented in Figure 4B were \( \sqrt{y} = \sqrt{8.15 + 0.033 \times x} \), (\( P = 0.97 \)) for the sine function estimates, corresponding with 89% and 3% increases in rates from 14° to 21°C, respectively. Fourthly, the relationship of the maximum elongation rates of the floral flushes to temperature, though possibly confounded by irradiation effects, had the anticipated positive trend (Figure 5B).

Once the maximum elongation rates had been standardised, the effects of irradiation on the rate could have been examined by plotting one against the other. This, however, is equivalent to plotting the non-standardised rates against the product of irradiation and temperature, which is the course we preferred (Figure 5C). With respect to both the Richards and sine functions, there were mid-range peaks in the rates with respect to the irradiation-temperature product. On the bases of the relationships of irradiation to temperature (\( I = -2.62 + 0.96 \times T, r^2 = 0.65 \) with respect to the Richards function; \( I = -8.74 + 1.24 \times T, r^2 = 0.61 \) with respect to the sine function), the peaks were at irradiation equivalents of 16.0 and 15.1 MJ m⁻² d⁻¹ for the Richards and sine functions, respectively. Note that the putative peaks for the vegetative and floral flushes were approximately the same.

**Floral induction**

Kwai May Pink buds are similar in size to those of Wai Chee. In Wai Chee, low temperatures have been shown to be effective in swelling buds 2 mm long (Batten and McConchie 1995). Estimates of the dates on which the buds of Kwai May Pink reached 2 mm were made using the Richards and sine functions. As a guide to the relative merits of the two fits, the deviations of the curves from the first measured length of each flush were analysed. The sum of squares was less for the Richards function than for the sine function (527 versus 575 mm²), but the Richards function tended to over-estimate the
lengths while the sine function did not (sign tests, \( P_{0.05} \)). For economy, only the estimates from the sine function were used. Weather was analysed for eleven day blocks, five days either side of the estimated day when the buds were 2 mm long.

In glasshouse experiments, Menzel and Simpson (1995) found that Kwai May Pink produced only vegetative flushes above 20°C. Our results are consistent with this, with only vegetative flushes occurring when the mean daily temperatures were above 20°C (Table 2). However, not all temperatures below 20°C induced flowering. Indeed, the emergence of the second vegetative flush on the pruned trees near Ballina was associated with the lowest mean, maximum and minimum temperatures in our study (Table 2). Furthermore, for these trees, the first spring day with a mean daily temperature above 20°C occurred 34 days after the first of the five buds had reached 2 mm in length, and 9 days after the last. The apparent anomaly might be related to irradiation: more radiation was received from clearer skies during early vegetative flush development than during early floral flush development (Table 2; t-tests, \( P_{0.05} \)).

**Effects of leaf stripping on subsequent flushing**

Five trees of Kwai May Pink were stripped of their leaves in autumn 1996 to see whether they would flower without mature leaves. From mid-April to early October the trees put on 1893 ± 197 flushes, all of which were vegetative. Five adjacent trees which were not stripped put on 509 ± 33 vegetative flushes and 54 ± 10 floral flushes. All of these five trees flowered to some extent, as did the other 23 non-stripped trees of Kwai May Pink within the orchard. Thus, there seems to be a crucial role for mature leaves in floral induction.

Table 2. Eleven day averages of temperatures, irradiation and radiation transmission (cloudiness) centred on the day on which the flushes reached 2 mm in length, as estimated from the sine function (Materials and Methods). The flushes correspond with the flushes in Figure 1. The values are given as means and standard errors, \( N = 5 \). An asterisk indicates that the mean is significantly different from the mean for the Ballina pruned second vegetative flush within the column (t-tests, \( P_{0.05} \)).

<table>
<thead>
<tr>
<th></th>
<th>Mean temp. (°C)</th>
<th>Mean max. temp. (°C)</th>
<th>Mean min. temp. (°C)</th>
<th>Irradiation (MJ m(^{-2}) d(^{-1}))</th>
<th>Radiation transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ballina</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control floral</td>
<td>18.1 ± 0.6*</td>
<td>23.6 ± 0.9</td>
<td>13.4 ± 0.5*</td>
<td>12.4 ± 1.4*</td>
<td>0.68 ± 0.04*</td>
</tr>
<tr>
<td>Pruned first vegetative</td>
<td>21.1 ± 0.2*</td>
<td>26.3 ± 0.3*</td>
<td>16.3 ± 0.3*</td>
<td>19.4 ± 0.7*</td>
<td>0.82 ± 0.04</td>
</tr>
<tr>
<td>Pruned second vegetative</td>
<td>15.5 ± 0.4</td>
<td>22 ± 0.3</td>
<td>9.4 ± 0.6</td>
<td>16.1 ± 1.2</td>
<td>0.82 ± 0.03</td>
</tr>
<tr>
<td><strong>Bundaberg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control floral</td>
<td>19.5 ± 0.5*</td>
<td>24.3 ± 0.4*</td>
<td>15.3 ± 0.6*</td>
<td>10.2 ± 0.3*</td>
<td>0.67 ± 0.02*</td>
</tr>
<tr>
<td>Pruned first vegetative</td>
<td>21.5 ± 0.8*</td>
<td>27.9 ± 0.8*</td>
<td>15.9 ± 1.1*</td>
<td>16.6 ± 0.6</td>
<td>0.80 ± 0.02</td>
</tr>
<tr>
<td>Pruned second vegetative</td>
<td>17.2 ± 0.6*</td>
<td>23.4 ± 0.8</td>
<td>11.5 ± 0.6*</td>
<td>12.9 ± 0.5*</td>
<td>0.72 ± 0.02*</td>
</tr>
</tbody>
</table>

**Discussion**

**Curve fitting**

The Richards logistic function was forced by translation through the nominal origin so that sensible estimates of the day on which the flush was 2 mm long could be made from relatively few observations. Without the modification, it was not uncommon for the estimate to pre-date the first evidence of bud development by months. By the nature of the function, there was a positive slope at the origin, and this might account for the tendency to over-estimate early flush lengths.
The sine function is much simpler than the Richards function, yet accounted for only slightly less of the mid-range variance, and produced more acceptable estimates of early flush lengths. Furthermore, simple meanings can be attached to the parameters, with r, a relative rate and t, a measure of asymmetry. There is an additional attraction, that over the range 0<t<2, where the curve is sigmoidal, slopes are zero at y = 0 and y = y_{max}. Gradual beginnings and endings are more appropriate to biological development than instantaneous switches.

Flush development

Vegetative flush elongation was related to irradiation, but not to temperature (Figure 4). The lack of an obvious response to temperature was probably partly a consequence of the small range of temperatures encountered, given that Batten and Lahav (1994) showed a tendency for increasing rates of leaf expansion from 15° to 35°C, and Olesen et al. (2000) found a weak but significant tendency for shoot elongation to increase from 18.5° to 24.8°C. With respect to irradiation, there was a mid-range peak at 15.9 MJ m² d⁻¹. The most likely explanation for such a peak is that it represents the conventional response of caulescent plants to increasing shade, whereby changes in resource partitioning promote stem elongation (Gilbert et al. 1995), resulting in higher absolute rates, until irradiation reaches such a low level that substrate limitation becomes dominant (Matsubara and Hiroki 1989; Sprugel et al. 1991).

The same basic arguments can be applied to the growth of the floral flushes (Figure 5), although the situation was more ambiguous, owing to the correlation of irradiation and temperature and to the clumping of data. The decline in the rates from mid to low irradiation for both the vegetative and floral flushes was consistent with a dependency of flush development on current assimilation (Matsubara and Hiroki 1989; Sprugel et al. 1991).

Once the panicles had been initiated, their development seemed to be governed by both an intrinsic developmental program, such that, near Bundaberg, the panicles of the pruned trees, which were initiated later than the controls, also matured later (Figure 1); and by the environmental conditions, such that there were large differences in panicle size (Figure 1; Table 1). Near Bundaberg, the controls flowered three weeks earlier than the pruned trees (Figure 1) but there was only a one week difference in the time of harvest. There is clearly only marginal advantage in starting fruit development in the earlier, cooler, duller part of spring.

Floral induction

Our results support the idea that weather conditions during the lag phase have little effect on bud determination: those trees which experienced the greatest chilling prior to bud expansion produced vegetative flushes. From glasshouse experiments, it is generally thought that temperatures above 20°C promote vegetative flushes, and temperature below, floral flushes (Batten and McConchie 1995; Menzel and Simpson 1995). Our results were consistent with these expectations in five out of six cases, but in one case (second flush of the pruned trees near Ballina) the trees flushed away vegetatively even though early flush development corresponded with air temperatures of 15.5°C (Table 2) and occurred well before the first 20°C day of spring.

Orchard management

Axillary buds grew about ten days after pruning. By pruning the trees when they had a red-green flush, the flushing cycles were quite different to the controls. This change delayed flowering near Bundaberg, and reduced it near Ballina.

These results are of practical interest to the lychee industry in that pruning can be used to regulate flowering. They are also of some concern. Pruning machines are commonly used within the industry
to control tree height. However, the work is usually done by contractors, who bring the machines to the farms, and who often have little flexibility in their work schedule. By pruning their trees on the basis of when the machines are available, growers may be in danger of training their trees to non-productive cycles.

More generally, our results could have implications for other recurrently flushing, terminal-bearing plants, such as the commercial mango, longan and rambutan crops.

References


The Richards logistic function

The general form of the Richards function (Causton and Venus 1982) is:

\[ y = y_{\text{max}} \cdot (1 + e^{b(j-x)})^i + c \]  
(A1)

where,  
\( y = \) dependent variable  
\( x = \) independent variable  
\( y_{\text{max}}, b, j, i \) and \( c \) = parameters

When \( x = 0 \):

\[ y = y_{\text{max}} \cdot (1 + e^{bj})^i + c \]  
(A2)

To ensure that the function passes through the origin (i.e. ensure that the flush has zero length at day 0) subtract (A2) from (A1):

\[ y = y_{\text{max}} \cdot [(1 + e^{b(j-x)})^i - (1 + e^{bj})^i] \]  
(A3)

In (A3), as \( x \to \infty \):

\[ y \to y_{\text{max}} \cdot [1 - (1 + e^{bj})^i] \]  
(A4)

It follows, for (A3) to have a maximum value of \( y_{\text{max}} \) it must be divided by \( [1 - (1 + e^{bj})^i] \). By doing this, and by replacing the parameters \( b \) and \( i \) with a single parameter \( v \) to avoid over-parameterization in the fitting, the equation in the text is achieved:

\[ y = y_{\text{max}} \cdot [(1 + e^{v(j-x)})^v - (1 + e^{vj})^v] / [1 - (1 + e^{vj})^v] \]  
(A5)

When the symmetric logistic equation (A1 with \( i = 1 \)) was varied in the same way and applied to the data in Fig. 1 the overall residual sum of squares for the 30 curves was 40 % greater than that for (A5), with the same number of estimated parameters. The first and second derivatives of (A5) are:

\[ \frac{dy}{dx} = y_{\text{max}} \cdot v^2 \cdot e^{v(j-x)} \cdot (1 + e^{v(j-x)})^{(v+1) / [1 - (1 + e^{vj})^v]} \]  
(A6)

\[ \frac{d^2y}{dx^2} = y_{\text{max}} \cdot (v \cdot e^{v(j-x)} - 1) \cdot v^3 \cdot e^{v(j-x)} \cdot (1 + e^{v(j-x)})^{(v+2) / [1 - (1 + e^{vj})^v]} \]  
(A7)

The second derivative is equal to zero when \( (v \cdot e^{v(j-x)} - 1) \) is equal to zero. Thus the maximum rate occurs when:

\[ x = j - \ln(1 / v) / v \]  
(A8)

The maximum rate is:

\[ \frac{dy}{dx_{\text{max}}} = y_{\text{max}} \cdot v \cdot (1 + 1 / v)^{(v+1) / [1 - (1 + e^{vj})^v]} \]
The sine function

The sine function can be written in a slightly more elaborate form than that written in the text, one which does not require the fixing of a commencement date:

\[ y = y_{\text{max}} \times \left\{ \sin\left(\pi \times (r \times x + b) - \left(\frac{\pi}{2}\right)\right) + 1 \right\} / 2 \]

(A9)

where, \( y = \) dependent variable
\( x = \) independent variable
\( y_{\text{max}}, r, b \) and \( t \) = parameters

This can be re-written as:

\[ (\arcsine(2 \times (y / y_{\text{max}}) - 1) + \left(\frac{\pi}{2}\right)) / \pi = a \times x + b \]

(A10)

By constraining \( y_{\text{max}} \), this transform can be dealt with on computer spreadsheets, using iterations of \((t)\) over a small range (see below), useful in the absence of a non-linear regression program. The first and second derivatives of (A10) are:

\[ dy/dx = y_{\text{max}} \times \pi \times \left\{ \sin\left(\pi \times (r \times x + b) - \left(\frac{\pi}{2}\right)\right) + 1 \right\} (1-t)/t \times \cos\left(\pi \times (r \times x + b) - \left(\frac{\pi}{2}\right)\right) / 2 \]

(A11)

\[ d^2y/dx^2 = y_{\text{max}} \times \pi \times \sin\left(\pi \times (r \times x + b) - \left(\frac{\pi}{2}\right)\right) \]

(A12)

The maximum growth rate occurs when:

\[ x = \frac{\left\{ \arcsine(1 - t) \right\} / \pi + (1 / 2) - b}{r} \]

(A13)

The maximum growth rate for \( 0 < t < 2 \), the range over which the function is sigmoidal, is:

\[ [dy/dx]_{\text{max}} = y_{\text{max}} \times \pi \times \left\{ (2 - t) / 2 \right\} (1-t)/t \cos\left(\arcsine(1 - t)\right) / (2 \times t) \]

(A14)

For \( t = 2 \) the maximum growth rate occurs when \( x = -b / r \), and can be calculated from the limit equation:

Let \( \delta \) be a very small number greater than zero, then

\[ \text{Limit (} x \rightarrow -b / r \text{)} = y_{\text{max}} \times \left\{ \sin((\pi \times r \times \delta) - (\pi / 2)) + 1 \right\} / 2 \]

\[ = y_{\text{max}} \times \left\{ (1 - \cos((\pi \times r \times \delta)) / 2 \right\} (1/2) / \delta \]

\[ = y_{\text{max}} \times \left\{ (2 - 2 \times \cos((\pi \times r \times \delta) / 2)) / 2 \right\} (1/2) / \delta \]

\[ = y_{\text{max}} \times \left( \sin((\pi \times r \times \delta) / 2) \right) / \delta \]

\[ = y_{\text{max}} \times \pi \times r / \delta \]

(A15)

For \( t = 0 \) and \( t > 2 \) \([dy/dx]_{\text{max}}\) is undefined.
Figure 1. The flushing of pruned and control Kwai May Pink lychee trees in near Ballina and Bundaberg. The symbols track the elongation of the longest flush to develop from the eight tagged branches on each of the five trees. Lines were fitted using the modified sine function. Broken lines indicate vegetative flushes, solid lines floral flushes.
Figure 2. Decline in the variation surrounding the estimates of irradiation (A) and temperature (B) with increasing averaging interval in pruning experiments with Kwai May Pink lychee. Open symbols and broken lines Bundaberg, closed symbols and solid lines Ballina. There were 203 and 246 days analysed for the two sites respectively, covering the elongation of all flushes. Radiation transmission was transformed (single or repeated arcsine) to satisfy conditions of constant variance and normality. Transmission was not related to solar declination (F-tests, $F_{0.05}$) and the variation was described by the variance. Temperature ($T$) was related to solar declination ($\delta$) at both sites (Bundaberg, $T = 22 + 0.27 \times \delta, r^2 = 0.42$; Ballina, $T = 18.6 + 0.21 \times \delta, r^2 = 0.41$) and the variation was described by the residual mean sum of squares. The fitted relationships for radiation transmission variance against averaging interval are, $\ln y = 0.133 - 0.788 \ln x, r^2 = 0.99$ (Bundaberg) and $\ln y = 0.030 - 0.652 \ln x, r^2 = 1$ (Ballina), and for temperature residual against averaging interval, $\ln y = 0.014 - 0.181 \ln x, r^2 = 1$ (Bundaberg) and $\ln y = 0.048 - 0.260 \ln x, r^2 = 0.98$ (Ballina).
Figure 3. Discrepancy between the Richards function and the modified sine function in the estimation of the day on which the maximum rate of flush elongation occurred for Kwai May Pink lychee. The results correspond with the vegetative and floral flushes in Figure 1.
Figure 4. Maximum elongation rates of vegetative flushes estimated from the Richards function (open symbols) and the sine function (closed symbols) in relation to irradiation (A) and temperature (B) for Kwai May Pink lychee. Irradiation and temperature were averaged over eleven days, five days either side of the estimated days on which the maximum rates occurred. The only significant ($P_{0.05}$) simple regressions were with respect to irradiation. The general form of the fitted functions is the first derivative of the symmetric logistic, $f(x) = a \cdot b \cdot e^{b(c-x)} \cdot (1 + e^{b(c-x)})^{-2}$, with the peak occurring at $x = c$. For the Richards function (broken line), $f(x) = y$, $a = 247$, $b = 0.267$, $c = 15.9$ and $r^2 = 0.47$ with $n = 15$. For the sine function (solid line), $f(x) = \sqrt{y}$, $a = 50.2$, $b = 0.286$, $c = 15.9$ and $r^2 = 0.61$ with $n = 15$. 
Figure 5. Maximum elongation rates of floral flushes estimated from the Richards function (open symbols) and the sine function (closed symbols) in relation to irradiation (A), temperature (B) and the irradiation-temperature product (C) for Kwai May Pink lychee. Irradiation and temperature were averaged over eleven days, five days either side of the estimated days on which the maximum rates occurred. The fitted relationships to Figure 5C (n =15) are of the form $f(x) = a \cdot b \cdot e^{b(c-x)} \cdot (1 + e^{b(c-x)})^{-2}$, where $f(x) = \sqrt{y}$, $a = 839$, $b = 0.0126$, $c = 309$, $r^2 = 0.69$, for the Richards function (broken line); and $f(x) = y$, $a = 1282$, $b = 0.0194$, $c = 291$, $r^2 = 0.76$, for the sine function (solid line).
Effects of Irradiation and Temperature on Lychee Flush Development

Summary

The recurrent flushing patterns of well-watered, well-fertilised Kwai May Pink lychee trees were studied using a field-based pruning trial. Staggered pruning resulted in staggered flush emergence, and this stagger was perpetuated through successive vegetative flushes, and through to the timing of floral flush emergence in winter. The earlier that floral flushes began to emerge on a tree in winter, the greater was the relative yield of that tree. The greater relative yields were related both to a higher proportion of branches bearing panicles, and to more fruit per panicle.

The maximum elongation rates of the vegetative and floral flushes were weakly related to irradiation and temperature, with the explained variance of the various regressions ranging from 15 to 41%. In contrast, the vegetative cycling rate (the reciprocal of the time between the emergence of successive flushes) was strongly related to the daily irradiation-temperature product. A model of this relationship was applied to long-term weather records from across the geographic range over which lychee is grown commercially along Australia’s north-eastern seaboard, to illustrate the latitudinal variation in flush development. For example, for a new flush to commence on the day of the winter solstice in the median year, the previous vegetative flush would need to have started in early March in northern New South Wales and in late March in north Queensland.

Long-term weather records were also used to estimate the latitudinal variation in the annual number of days of florally inductive weather (mean daily temperatures <20°C) along the eastern seaboard of Australia. Irregular flowering of lychee in many areas is partly the result of a lack of coincidence of early flush development with florally inductive weather conditions. In coastal northern Queensland, however, there may be years in which inductive weather conditions do not occur. This is why yields can be very erratic in locations such as Cairns and Gordonvale. In contrast, yields are much more reliable at elevation in northern Queensland (e.g. Koah and Mareeba).

Commercial Implications. A model has been developed to assist lychee growers to prune their trees at the most appropriate time after harvest. The optimum time of pruning varies with latitude along the eastern coastline from Mareeba and Cairns in northern Queensland to Ballina in northern New South Wales. The model allows for one or two growth flushes before winter in warmer areas and one flush in cooler areas. In any one location, the optimum time of pruning does not appear to vary dramatically across different cultivars. The model is a significant advance as it takes into account the effect of weather on the flushing rate of lychee in different localities. Previous research did not provide recommendation for individual growing areas.

Introduction

Lychee is an evergreen, recurrently flushing tree. The minimum interval between successive flushes is approximately six weeks (Batten and Lahav 1994), but the interval can be much longer, depending on the weather conditions and the physiological state of the plants. Whether a flush is vegetative or floral, largely depends on the weather conditions during early flush development (Batten and McConchie 1995; Olesen et al. 2000). Inflorescences are generally initiated when temperatures are below 20°C during this period.

In the field, the period of inductive weather is often small, and sufficiently small for it to fall between the determinant stages of successive flushes. A lack of synchrony between early flush development and inductive weather seems to be the main reason for the irregular flowering of lychee.
It is clearly of commercial interest to be able to recognise non-productive flushing cycles within orchards, so that remedial measures might be taken. In this regard, we present here the results of a field-based staggered pruning trial, from which the dependency of flush development on irradiation and temperature was modelled in several ways. One of these models was applied to long-term weather records from across the geographic range over which lychee is grown commercially, to estimate the best date for the commencement of a flush in summer and autumn, for flush emergence and flowering in winter. We also use the weather records to estimate the number of days of inductive weather in different locations.

Many of Australia’s native trees and shrubs have a similar flushing habit to lychee and require cold weather for successful flowering (King 1998). Since many of these species have problems flowering and setting seed, our work may benefit Australia’s native forests and woodlands.

Materials and Methods

The experiment was conducted at the Tropical Fruit Research Station, Alstonville in northern New South Wales (29°S 153°E). Fourteen trees, watered and fertilised to industry standards (Greer 1995), were pruned in pairs on seven occasions from September 11, 1996 until March 6, 1997. The pruning was severe, involving the removal of major branches such that the tree heights were reduced from 7 to 2.5 m. All the remaining branches were tip-pruned to remove the most recent flush. By the end of the pruning, the number of leaves per tree had been reduced from several thousand to a few hundred. Four branches were tagged on each tree, 1.5 m above the ground, in the canopy arc from north-east to north-west. The flush development of these branches was followed at approximately 10 day intervals until October 24, 1997. On October 13, 1997, counts were made of the number of vegetative and floral branches, and on January 28, 1998, counts of the number of fruit. New South Wales Agriculture provided records of temperature and irradiation (400-1100 nm) for the research station.

Flush elongation was characterised using the sine function described by Olesen \textit{et al.} (2000), with the same constraints. The sine curves, and the other curves used, were fitted by non-linear regression, using the Marquardt-Levenberg algorithm in \textit{SigmaStat} (Jandel Corporation). Only significant regressions were incorporated into graphs. All the fitted curves presented satisfied $P_{0.05}$ conditions of normality and constant variance.

The long term weather records used are of both actual and generated values, and come from the work of Meinke \textit{et al.} (1995). The locations and latitudes of the weather stations are given in Table 1. Solar declination was calculated using Spencer’s equation (Iqbal 1983).

Table 1. Locations of long-term weather records along the north-eastern seaboard of Australia.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude (°S)</th>
<th>Longitude (°E)</th>
<th>Years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mossman</td>
<td>16.5</td>
<td>145.4</td>
<td>1911-1993</td>
</tr>
<tr>
<td>Cairns</td>
<td>16.9</td>
<td>145.8</td>
<td>1888-1993</td>
</tr>
<tr>
<td>Mareeba</td>
<td>17.0</td>
<td>145.4</td>
<td>1904-1993</td>
</tr>
<tr>
<td>Innisfail</td>
<td>17.5</td>
<td>146.0</td>
<td>1988-1993</td>
</tr>
<tr>
<td>Ingham</td>
<td>18.7</td>
<td>146.2</td>
<td>1893-1993</td>
</tr>
<tr>
<td>Ayr</td>
<td>19.6</td>
<td>147.4</td>
<td>1888-1993</td>
</tr>
<tr>
<td>Proserpine</td>
<td>20.5</td>
<td>148.5</td>
<td>1889-1993</td>
</tr>
<tr>
<td>Mackay</td>
<td>21.2</td>
<td>149.1</td>
<td>1891-1993</td>
</tr>
<tr>
<td>Nebo</td>
<td>21.7</td>
<td>148.7</td>
<td>1888-1993</td>
</tr>
<tr>
<td>Bundaberg</td>
<td>24.9</td>
<td>152.4</td>
<td>1888-1993</td>
</tr>
<tr>
<td>Gin Gin</td>
<td>25.0</td>
<td>152.0</td>
<td>1901-1993</td>
</tr>
</tbody>
</table>
Results and Discussion

Phenology

Pruning stimulates growth of the axillary buds (Olesen et al. 2000). The staggered pruning resulted in staggered bud growth, and staggered vegetative flushing (Figure 1A). There was little evidence of seasonality in the final length of the vegetative flushes, with $r = 0.24$ (probability = 17%, $n = 35$) for the Pearson correlation of final length against the declination at the time of flush emergence (i.e. when the flushes were 2 mm long, as estimated from the fitted sine function).

The later it was that the last pre-winter vegetative flush emerged, the less likely it was for the subsequent flush to flower (Figure 1B). The reason for this seems to have been that the subsequent flush was also later (Figures 1A, B and C), and unlikely to encounter cool weather.

The linear regression fitted to Figure 1C had a slope of one and an intercept of 126, which means that the vegetative flushes that commenced from early February to mid-April were followed by floral flushes approximately 126 days later. From Olesen et al. (2000), those trees pruned in March 1995 near Ballina near the Tropical Fruit Research Station, had $167 \pm 6$ days between the emergence of the first and second flushes, while those pruned in March 1995 near Bundaberg had $135 \pm 4$ days between flushes. Thus, there seem to be substantial year and locality differences.

The earlier a tree flowered, the more fruit it held at harvest (Figure 1D). The reason for this seems to have little to do with the size of the trees, as the number of fruit per panicle was not correlated with the total number of branches per tree ($r = -0.01$, probability 0.97). Nor does it seem to have much to do with the order in which the trees were pruned, as the pruning dates were not correlated with the floral flush emergence dates (Spearman $r = 0.30$, probability 0.29). The reason may be related to the size of the inflorescences, as these tend to be larger, the earlier a floral flush commences (Olesen et al. 2000). It may have been also related to variations in the proportions of male and female flowers (Menzel and Simpson 1988), pollination (McConchie and Batten 1991), or resource competition within the trees.

Given that the earlier a tree flowered, the greater was the proportion of branches to flower (Figure 1B), and the greater was the number of fruit produced per panicle (Figure 1D), it follows that the greater was the relative yield (i.e. on average, more fruit per branch).

Maximum elongation rates

The day on which the maximum rate of elongation occurred was estimated from the fitted sine curve. To relate the maximum rate to irradiation and temperature, the daily averages of the latter two were calculated for the 11 consecutive days starting from the fifth day before the estimated day on which the maximum rate occurred (Olesen et al. 2000).

For the vegetative flushes, irradiation and temperature were not significantly correlated (Pearson $r = 0.26$, probability 13%) and were treated as independent. Neither variable accounted for much of the variation in maximum elongation rates. With respect to irradiation, Olesen et al. (2000) found a mid-range peak in the maximum elongation rates which they ascribed to a conventional shade response. Using a similar regression here, we also found a significant mid-range peak ($P_{0.05}$; Figure 2A), although it only accounted for 19% of the variance. With respect to temperature (Figure 2B), a non-

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude (°S)</th>
<th>Longitude (°E)</th>
<th>Years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiaro</td>
<td>25.7</td>
<td>152.6</td>
<td>1894-1993</td>
</tr>
<tr>
<td>Nambour</td>
<td>26.6</td>
<td>153.0</td>
<td>1894-1993</td>
</tr>
<tr>
<td>Murwillumbah</td>
<td>28.4</td>
<td>153.4</td>
<td>1891-1993</td>
</tr>
<tr>
<td>Harwood</td>
<td>29.4</td>
<td>153.3</td>
<td>1916-1993</td>
</tr>
<tr>
<td>Grafton</td>
<td>29.7</td>
<td>152.9</td>
<td>1880-1993</td>
</tr>
</tbody>
</table>
linear regression that gave a straight line on back-transformation was significant \((P_{0.05})\), but only explained 15\% of the variance. On the basis of this regression, the maximum elongation rate increased by 89\% from 19 to 24°C.

For the floral flushes, irradiation and temperature were positively correlated (Pearson \(r=0.54\), probability 4.7 \%). Olesen et al. (2000) accounted for such a correlation by considering the maximum elongation rate against the irradiation-temperature product (Figure 2E), rather than the two variables separately (Figures 2C and D). They found a mid-range peak, possibly representing a shade response. Using a similar approach here, we found a mid-range peak that accounted for 41\% of the variance.

That the mid-range peaks in the maximum elongation rates for the vegetative and floral flushes, against irradiation and the irradiation-temperature product, respectively, were weaker than those found by Olesen et al. (2000) might have been related to the greater severity of our pruning and to the greater openness and spacing of our canopies.

**Flush determination**

Floral induction has been shown to occur in swelling buds up to 2 mm (Batten and McConchie 1995; Olesen et al. 2000). As a guide to the weather conditions during bud determination we follow the method of Olesen et al. (1999), whereby the estimated day on which the longest flush to develop on each tree during each flushing episode reached 2 mm in length, was used as the mid-point of an 11-day block, for which mean temperature and mean daily irradiation were calculated.

Floral induction occurred at low temperatures and low radiation loads (Figure 3A). The critical temperature was something less than 19°C, which was very close to the 20°C estimated by Menzel and Simpson (1995) for potted plants grown in air-conditioned glasshouses receiving less than full daylight, and also close to the field estimates made by Olesen et al. (2000).

Batten and McConchie (1995) suggested that fluctuating temperatures might enhance flowering. However, there is no evidence for this in the results presented here (Figure 3B) nor in those presented by Olesen et al. (1999). Indeed, Menzel and Simpson (1995) found that potted marcots of Kwai May Pink grown at 25°/10°C cycles flowered less than those grown at 20°/15°C, even though both groups experienced a mean temperature of 17.5°C.

**Vegetative cycling rates**

Flush duration was calculated as the time from when the first of the four measured flushes reached 2 mm in length during one flushing episode, to the equivalent stage during the next flushing episode. The same developmental signposts were used to calculate the mean temperature and mean daily irradiation during flush development. The plot of temperature against irradiation for the development of each the vegetative flushes illustrates that the two variables were closely correlated (Figure 4A), as was expected from the staggered pruning and the consequent overlap of developmental times. The ‘hook’ at high radiation loads was related to a particularly cloudy late spring and early summer in 1996.

Following the approach used to examine flush elongation when dealing with correlated independent variables, cycling rates \((1/\text{flush duration})\) were expressed against irradiation, temperature and the irradiation-temperature product (Figures 4B, C and D). In addition, a second irradiation-temperature product was used (Figure 4E), based on hourly instead of daily records. The hourly product could be considered to give greater weight to photosynthetic metabolism. The asymmetric logistic regressions for the four plots all accounted for much of the variation in rates, and none of the regressions could be confidently preferred as a predictive model.

The regression equations were then used to predict the cycling rates of those trees pruned near Ballina and Bundaberg in the study by Olesen et al. (1999). The sums of squares of the deviations (Figures 4B-E) were: \(14.6 \times 10^{-6} \text{ d}^{-2}\) for irradiation; \(34.6 \times 10^{-6} \text{ (solid line)}\) and \(26.7 \times 10^{-6} \text{ (broken line) d}^{-2}\) for
temperature; \(6.3 \times 10^{-6} \, \text{d}^{-2}\) for irradiation-temperature (daily); and \(8.6 \times 10^{-6} \, \text{d}^{-2}\) for irradiation-temperature (hourly). The product equations seem to be more reliable.

Effects of latitude on flush development

The cycling rate versus the daily irradiation-temperature product equation of Figure 4D was applied to the long-term weather data from the locations listed in Table 1. It was used to estimate, at each location and for each year of record, flush commencement dates such that one and two vegetative flushes were completed on the day of the winter solstice. The estimate of the commencement date for the flush immediately prior to the winter solstice (the autumn flush) was calculated by back-counting from the solstice until the reciprocal number of days equalled the cycling rate corresponding to the mean irradiation-temperature product. The same procedure was used to estimate the commencement date of the second vegetative flush back from the solstice (the summer flush), except that the estimated commencement date of the autumn flush was used as the starting point.

The earliest and median commencement dates for the autumn flush occurred earlier in the year with increasing latitude (Figure 5A). Such a result was to be expected from the gradients in irradiation and temperature. With respect to the commencement dates of the summer flush, the relationships with latitude were nearly parallel to those for the first flush back. This is an indication that for the summer flush the plants were cycling near their maximum rates at all locations.

This information can be used in the management of flushing within lychee orchards, as the key to successful flowering is the promotion of winter flush emergence, so that early flush development coincides with inductive weather conditions (Olesen et al. 2000). Lychee is a day neutral plant (Nakata and Watanabe 1966) and, at present, temperature is the only environmental variable strongly implicated in flowering. For Kwai May Pink, mean daily temperatures below 20°C are required (Menzel and Simpson 1995). Using this criterion, estimates were made of the latitudinal variation in the annual number of inductive days along Australia’s north-eastern seaboard (Figure 5B). In coastal northern New South Wales (lat. 29°S), there are over 100 days of inductive weather, but the number declines rapidly towards the equator, so that for Cairns in northern Queensland (lat. 17°S), the median year had only 17 days, while for some years, there was none.

A number of caveats need to be made for the above results. Firstly, at higher latitudes many of the supposed inductive days are too cold for flush emergence to occur. Secondly, it is not known how many inductive days are needed together in order to be effective, nor how this number might depend on the physiological state of the plant. This point is of particular concern at low latitudes, where inductive days are often intermittent. Thirdly, air temperature is perhaps not an entirely reliable guide to inductive weather conditions in the field, given that it is the temperature of the leaves that is probably most important, based on results from mango (Nunez-Elisea and Davenport 1992; 1995). Fourthly, care needs to be taken in relating the results to cultivars other than Kwai May Pink, because physiological differences between cultivars in temperature thresholds and optima are known (Batten and Lahav 1994).

References


Olesen, T., Menzel, C. M., Batten, D. J., McConchie, C. A. and Jones, P. N. (2000). Effects of pruning on the flushing cycles and flowering of lychee. *Australian Journal of Botany*
A. Flush length (mm)

B. Pre-winter vegetative, and winter floral, flush emergence

C. Emergence of pre-winter flush

D. Winter floral flush emergence

Per cent of branches flowering

Number of fruit per panicle
Figure 1. Flushing, flowering and fruiting of pruned Kwai May Pink lychee trees in northern New South Wales. (A) Successive flushes of trees pruned on September 11 (broken line) and October 30 (solid line), 1996. For each tree, the flush described is the longest one to develop on the four tagged branches during each flushing episode. (B) The proportion of branches flowering in spring 1997 in relation to the emergence of the last vegetative flush before winter (closed circles) and the emergence of the subsequent floral flush (open circles). The times of emergence were calculated as the dates on which the earliest of the four tagged flushes on each tree reached 2 mm in length, as estimated from the sine function. The fitted curves, with x as the day of the year, are $y^2 = 8173 * (1 + e^{0.19 * (x - 73.1)})^{-1}$ for the vegetative flush ($r^2 = 0.73, n=14$); and $y^2 = 7578 * (1 + e^{0.36 * (x - 208.2)})^{-1}$ for the floral flush ($r^2 = 0.73, n = 14$). (C) Dependency of the time of floral flush emergence on the time of the emergence of the previous vegetative flush. The times of emergence were calculated as in B. The fitted curve is $y = x +126$, with x as the day of the year ($r^2 = 0.54, n = 14$). (D) The number of fruit at harvest divided by the number of floral branches in the previous spring, expressed against floral flush emergence, as per B. $\sqrt{y} = 3.16 - 0.013 * x$, with x as the day of the year ($r^2 = 0.43, n =14$).
Figure 2. Dependency of the maximum elongation rates of the vegetative (n = 35) and floral (n = 14) flushes of the lychee cultivar Kwai May Pink on irradiation and temperature. Daily irradiation and temperature are given as the means for the 11 day blocks from 5 days before the estimated day on which the maximum rate occurred. The fitted curves are: (A) \( y = a \cdot (b \cdot e^{c \cdot x}) \cdot (1 + e^{b \cdot (c - x)})^2 \), with \( a = 188, b = 0.26, c = 18.6 \left( r^2 = 0.23 \right) \); (B) \( y^{0.25} = (1.14 \cdot x - 15.2)^{0.25} \), \( r^2 = 0.18 \); (E) \( y = a \cdot (b \cdot e^{b \cdot (a - \sqrt{x})}) \cdot (1 + e^{b \cdot (a - \sqrt{x})})^2 \), \( a = 17.4, b = 0.86 \left( r^2 = 0.45 \right) \). Those curves with mid-range peaks are first derivative logistics.
Figure 3. (A) Average daily means of temperature and irradiation at the putative time of bud determination (as either vegetative of floral) of Kwai May Pink lychee. Each average is for the 11 days from 5 days before the estimated day on which the flush reached 2 mm in length. Only the earliest measured flush to emerge from each tree during each tree flushing episode was used (n = 49). (B) The temperature range over the same interval, against the mean temperature.
Figure 4. Dependency of the vegetative cycling rate (1/flush duration) of the lychee cultivar Kwai May Pink on irradiation and temperature in northern New South Wales (circles). Flush duration was calculated as the time from when the first of the four measured flushes reached 2 mm in length during one tree flushing episode, to the equivalent stage during the next. The fitted curves are asymmetric logistics of the general form $y = a \ast (1 + e^{b \ast (c - x)})^b$, with n = 35. (A) The average daily irradiation and temperature during each vegetative flush. (B) Cycling rate against average daily irradiation, $a = 0.0163$, $b = 0.434$, $c = 16.7$ ($r^2 = 0.74$). (C) Cycling rate against average temperature. For this plot the parameters $a$ and $b$ of the logistic curve were overly dependent on each other, such that reliable estimates could not be made of either. Consequently two curves were fitted, one fixing $a = 0.0167$ (from D), giving $b = 0.561$ and $c = 19.9$ ($r^2 = 0.71$; broken line); and the other fixing $b = 0.5$, giving $a = 0.0222$ and $c = 22.3$ ($r^2 = 0.83$; solid line). (D) Cycling rate against the average product of the total daily irradiation and the mean daily temperature, $a = 0.0167$, $b = 0.0552$, $c = 492.3$ ($r^2 = 0.80$). (E) Cycling rate against the average product of the total hourly irradiation and the mean hourly temperature, corrected to a daily rate, $a = 0.0159$, $b = 0.0562$, $c = 510.6$ ($r^2 = 0.77$). For Figures 4B-E, the squares and triangles are the results for the pruned trees near Ballina and Bundaberg, respectively, from Olesen et al. (2000), and were not used in the regressions.
Figure 5. (A) Variation in flush commencement dates with latitude, such that one and two flushes were completed on the day of the winter solstice (June 21). Estimates were made by applying the fitted equation to Figure 4D for Kwai May Pink lychee to long term weather records taken or derived (Meinke et al. 1995) from weather measurement made at the locations listed in Table 1. Triangles designate one flush out from the winter solstice, circles two. Open symbol designate the median commencement date for all the years of record, closed symbols the earliest commencement date. The linear regressions from top to bottom are: (1) $y = 43.9 - 2.17 \times x$, ($r^2 = 0.64$); (2) $y = 60.1 - 1.99 \times x$, ($r^2 = 0.81$); (3) $y = 103.7 - 1.90 \times x$, ($r^2 = 0.71$); (4) $y = 123.2 - 2.06 \times x$, ($r^2 = 0.85$); where $y$ is the day of the year, $x$ is latitude and $n = 16$. (B) For the same records, the median (closed circles) and maximum (open diamonds) and minimum (open squares) number of days per year with mean daily temperatures $< 20^\circ C$. The linear regression for the median values is $y = 14.5 \times x - 222$, ($r^2 = 0.98$), while those for the maximum and minimum values are $y = 14.7 \times x - 200$, ($r^2 = 0.96$) and $y = 13.6 \times x - 230$, ($r^2 = 0.97$), respectively.
Assessing a Model of Lychee Flush Development

Summary

Pruning trials were conducted on Kwai May Pink lychee in two commercial growing areas of Queensland to assess the model of vegetative flush development. As indicated above, the model was based on data collected near Ballina in northern New South Wales (lat. 29°S), while the assessments were made near Mareeba in north Queensland (lat. 17°S) and near Bundaberg in southern Queensland (lat. 25°S). The assessment was based on a comparison of the dependency of the extent of flowering on the date of pruning, as expected from the model, with the observed variation in flowering.

On 22 March, 1995, trees near Mareeba were either tip-pruned to remove all of the most recent, very young flush, or not pruned (controls). Pruning was repeated on 18 March, 1996 and then again on 20 March, 1997. In 1998, other groups of trees were either pruned, just once, every 10 days or so from 29 January to 26 March, or not pruned, giving a total of eight treatments. Near Bundaberg, trees were pruned in separate experiments on 8 March in 1995, on 26 February in 1996, and on 3 February, 26 February and 26 March in 1997, with non-pruned trees as controls. Records were made of the intensity of flowering in September; tree yields, as either total fruit weight or fruit numbers, in November or December; and the sizes (lengths, breadths, depths of canopies) or relative sizes of trees at harvest.

For the 1998 staggered pruning trial near Mareeba where the trees were pruned every 10 days, the sinusoidal time-courses of flowering and yield against pruning date had a period of 62 days, a minimum on 11 February and a maximum on 14 March, in accord with the expectations of the model developed at Alstonville. These results translate into pruning dates of early March or early January, giving one or two vegetative flushes before winter, respectively. The results from the 1995-97 Mareeba trials were also consistent: the prediction from the model was for ≈ 50% floral success, in practice, flowering for the three years was good, then fair, then negligible, relative to the controls. The corresponding relative yields were 94%, 65% and 0%.

The pruning times from the model for trees growing near Bundaberg were: mid-February for a guaranteed single flush before winter; and early March for the median of one flush before winter. Poor flowering was expected from trees pruned from late January to early February and from mid- to late March. Those trees pruned in early February and in late March in 1997 did, as expected, flower weakly and crop poorly. Those trees pruned in either late February or early March from 1995-97 all flowered and cropped as well as the control trees, which was a somewhat better performance than predicted, though the results are not necessarily inconsistent with the model.

Overall, the model gave good approximations to the latitudinal variations in flushing and flowering. Consequently, from it, practical estimates of pruning times can be made. These results demonstrate the lychees can be pruned with similar yields on a canopy surface basis to non-pruned trees, but have the added benefits associated with smaller trees – easier harvesting, netting and spraying. Trees can also be planted at close spacings. These all add up to greater returns for lychee growers.

Commercial Implications. A model to predict the optimum time of pruning for lychee across the eastern coastline of Australia was evaluated in commercial orchards in Mareeba and Bundaberg. The model was shown to give a good estimate of flushing patterns and flowering when the trees were pruned at different times in the two locations. It can thus be used as a reliable guide for calculating the best time for pruning in the different lychee growing areas in northern Australia.
**Introduction**

Lychee grows by recurrent flushing (Olesen et al. 2000a), such that branch elongation is episodic, not continuous. Generally, if the weather is warm during early flush development, above a daily mean of 20°C (Menzel and Simpson 1995), then the shoots will be vegetative. If, however, the weather is cool, then the flush will be an inflorescence (panicle). In the latter case, subsequent branch development occurs from axillary buds below the panicle.

The recurrent flushes of lychee are not haphazard, but related to the prevailing weather conditions and the physiological state of the trees. For well-fertilised, well-watered trees, the interval from the start of one vegetative flush to the start of the next (vegetative or floral) flush depends largely on irradiation and temperature. This dependency has been used to model latitudinal variations in vegetative flush development along Australia’s eastern seaboard where lychee is grown commercially (Olesen et al. 2000b). The model can be used to make modest predictions of the likelihood of winter flush emergence, and hence the likelihood of good flowering, from the phase of the flushing cycle in the previous months.

Tip-pruning can be used to alter the flushing cycle of lychee (Olesen et al. 2000a). In healthy trees, buds emerge about 10 days after pruning during summer and autumn, but a little later in winter, owing to the lower temperatures and radiation loads. It follows that a potential exists for tip-pruning to be used in conjunction with the model to train trees into more productive developmental patterns. While this might seem to be most simply done by pruning trees going into winter, forcing the trees to flower on the cut surface, the remaining leaves are too old to support a good crop. The strategy, then, is to achieve some canopy renewal after pruning, and have flowering occur in a later cycle.

We present the first assessments of the flush development model as a management tool. The model was based on data collected near Ballina in northern New South Wales (lat. 29°S), near the southern limit of production (Olesen et al. 2000b). Mindful that the data might contain a regional bias, assessments were made near Mareeba in north Queensland (lat. 17°S), near the northern limit of production, and near Bundaberg in southern Queensland (lat. 25°S). The assessment of the model near Mareeba largely involved a staggered pruning over late summer and early autumn, which was analysed against an expectation of sinusoidal variation in flowering with respect to the date of pruning: those trees pruned in January and March were expected to complete two and one vegetative flushes by winter, respectively, and therefore flower; while those pruned in mid-February were expected to flower poorly because of a second vegetative flush in late autumn, which was unlikely to mature before the spring. Temperatures in spring are generally not cool enough for flowering in lychee (Menzel and Simpson 1995). Near Bundaberg, the pruning trials were less extensive, with the pruning dates focused around the expected locations of the peaks and troughs of floral success.

The effects of pruning on flowering and yield of lychee trees have been studied in Florida (Young 1977), Taiwan (Yen and Tien 1985), Israel (Goren 1990) and Australia (Menzel et al. 1996). Trees were pruned in summer, autumn or winter, but responses were mixed. None of these authors pruned their trees with the idea of achieving a single or double flush before winter.

**Materials and Methods**

**Northern Queensland**

Location. The experiments were conducted in a commercial orchard of Kwai May Pink lychee planted in 1987 near Mareeba in north Queensland (17°S 145°E) on a brown sandy loam overlying a clay. The trees were watered and fertilised as per industry recommendation (Greer 1990).

Pruning trials, March 1995-97. Ten trees were selected and randomly divided into two groups of five. On 22 March, 1995, the trees of one group were lightly tip pruned with a mechanical pruner to remove
all of the most recent, very young flush. The trees of the other group were not pruned, and acted as controls. Pruning was repeated on 18 March, 1996 and then again on 20 March, 1997. Yields were measured in December as the number of fruit per tree. At the end of the season, the trees were visually ranked by size.

Staggered pruning trial, 1998. Forty trees were selected and randomly divided into eight groups of five. Seven of the groups were allocated a date on which the trees would be pruned, while the trees of the eighth group acted as controls. The first pruning was on 29 January and the last on 26 March. Pruning was more severe than in 1995-97, with up to 0.5 m removed from each branch. The numbers of floral branches per tree were scored in the September. In November, each tree was scored for the number of fruit, and for the depth, breadth and width of its canopy.

Southern Queensland

Experiments were conducted in a commercial orchard of Kwai May Pink planted in 1987 near Bundaberg in southern Queensland (25°S, 152°E) on a shallow sandy loam. The trees were watered and fertilised as described above, but were much smaller than those in north Queensland. In 1995, 10 trees were selected and randomly divided into two groups of 5. On 8 March, trees of one group were lightly tip-pruned to remove the last flush. The other group was left as a control. Pruning was repeated on February 26, 1996 with another group of 10 trees. On 3 February, 1997, 20 trees were selected and evenly divided into two groups, one of which was pruned, the other of which was left as a control. The procedure was repeated in 1997 on 26 February and 26 March, with 20 and 18 trees, respectively. Pruning was more severe in 1997 than in 1995 or 1996, with about 1 m taken from the tops of the trees. Canopy surface area (except in 1995), and yield as weight or number of fruit per tree were recorded in December or January.

Analyses

Curves of flowering and yield versus date of pruning for the 1998 staggered pruning trial near Mareeba were fitted by non-linear regression, using the Marquardt-Levenberg algorithm in SigmaStat (Jandel Corporation). Only significant regressions were incorporated into graphs. Both the fitted curves presented satisfied $P_{0.05}$ conditions of normality and constant variance.

The sinusoidal curves in Figure 1 are of the general form:

$$y^n = a \cdot \cos(\varphi + v \cdot \sin \varphi) + b$$

where: $\varphi = 360 \cdot (x - d) / c$; a measure of angle in degrees

- $x$ is the day of the year
- $a$ is the amplitude
- $b$ is the vertical displacement
- $c$ is the flushing period in days
- $d$ is the phase offset for the cycle
- $v$ is an angular distortion factor measured in degrees
- $n$ is a transform factor

(Batschelet 1981)

For the sinusoidal curves, the parameters were chosen to give the greatest compliance with the assumptions of normality and constant variance.

SigmaStat was also used to fit the regression to Figure 2, and to compare various treatments by means of the non-parametric rank sum test, analysis of variance or pairwise t-tests ($P_{0.05}$). Data are presented as means $\pm$ s.e.

Canopy dimensions were used to define half an irregular ellipsoid, the surface area of which was deemed to be the surface area of the canopy. There is no analytical solution to the surface area of an
irregular ellipsoid, so approximations were made using nets of triangles (Lang 1991). Canopy surface areas were used to compare tree sizes, and in the expression of relative yields.

**Results and Discussion**

**Northern Queensland**

Comparison of staggered pruning with model of flushing. From the model presented by Olesen et al. (2000b), there was a 50% likelihood of completing 2 vegetative flushes by the winter solstice for trees growing near Mareeba if buds emerged on 26 January, and 1 vegetative flush if buds emerged on March 29. To achieve bud break on these dates, trees would need to be pruned approximately 10 days earlier. Consequently, peak flowering was expected from trees pruned around the mid-January or mid-March, and the poorest flowering, approximately mid-way between these times. The cycle of peaks and troughs in the extent of flowering was expected to have a period of 62 days. From the long-term weather records from Mareeba, which formed part of the basis of the model, the maximum, the 90 percentile, the 10 percentile and minimum expected cycling periods were 75, 62, 60 and 60 days respectively.

By analysis of variance \((P_{0.05})\), there were significant differences between the 8 groups of trees with respect to flowering. When the control trees \((88 \pm 4\% \text{ flowering})\) were compared in pairwise t-tests \((P_{0.05})\) with the trees of the 7 pruned groups, only those trees pruned on February 10 had a significantly lower proportion of branches flowering (Figure 1a).

The sinusoid fitted to the time-course of flowering against pruning date (Figure 1a) had a period of 62 days, a minimum on February 11 and a maximum on 14 March, in accord with the expectations outlined above. The peak of the fitted curve was broad and the trough steep, probably indicating that the winter was long relative to the range of phasic variation in flush development. The explained variance of the sinusoid was somewhat low at 30\%, possibly because of variations in flush development within treatments. Greater characterisation of the February and April troughs and the January peak would have enhanced the parameter estimates.

Yields from the staggered pruning trial. The control trees \((45.7 \pm 5.1 \text{ m}^2)\) had significantly (t-test, \(P_{0.05}\)) larger canopy surface areas than the pruned trees \((39.7 \pm 5.0 \text{ m}^2)\). Consequently, yields were compared per unit surface area. The control trees had 71 \pm 7 fruit \text{ m}^{-2}. The yields of the control trees were not significantly different from the yields of the trees pruned on 29 January, 18 February and 11 March, but significantly greater than the trees pruned at other times (Figure 1b; t-tests, \(P_{0.05}\)).

As with the sinusoid for flowering, the sinusoid for yield (Figure 1b) had a period of 62 days, a minimum on 11 February and a maximum on 14 March. However, the yield trough was much broader than the flowering trough. This is indicative of a non-linear relationship between yield and flowering when expressed on an individual tree basis (Figure 2), possibly related to the size of the inflorescences (Olesen et al. 2000a); variations in the proportions of male and female flowers (Menzel and Simpson 1988); pollination (McConchie and Batten 1991); seed viability; or resource competition within trees. The link between yield and flowering largely accounts for the low amount of variance (24\%) explained by the yield sinusoid.

Pruning response across years. Weather conditions vary considerably from one year to the next, and this variation is sufficiently great to affect rates of flush development (Olesen et al. 2000b) and the response to pruning. To illustrate this point, the data from 1998 were supplemented with earlier results. The control trees flushed in mid-March, which corresponds with pruning in early March. In all years, the control trees flowered and yielded heavily (Table 1). The trees pruned on 18 March (1996 and 1998), 20 March (1997) or 22 March (1995), commenced flushing around the end of March. There was good flowering of these trees in 1995, moderate flowering in 1996 and 1998, and negligible flowering in 1997. As mentioned above, the trees pruned on 18 March, 1998 had lower
relative yields than the controls. For the other years, there were no significant differences in tree size between the control and pruned trees (rank sum, $P_{0.05}$), and the total yields could be directly compared. The pruned trees had similar yields to the control trees in 1995, but lower yields in 1996 and 1997 (t-tests, $P_{0.05}$). The pruning dates were close to that estimated from the model for a 50% likelihood of a single flush by the winter solstice (ca. 19 March, see above). It would seem, then, that the predicted likelihood of flush completion corresponds fairly well with the likelihood of flowering and the relative size of the crop. Earlier pruning appears to provide more consistent production in this environment (early January or early March).

Olesen et al. (2000b) also presented their model with respect to the expected completion of at least one flush by the winter solstice. From the model, this expectation is met near Mareeba with buds emerging on 12 March. This date is close to the day that the control trees started flushing in all years. Since these trees cropped consistently, it may be that the model configuration based on the completion of at least one flush gives a good guide to preferred flush emergence times. Bud break around 12 March translates into pruning in early March, or, more tentatively, early January, and these are the preferred pruning times for the location on current evidence. They might also be the preferred pruning times for the locality, given the gradual way in which flush development varies with latitude (Olesen et al. 2000b).

Table 1. Effect of pruning on yield (number of fruit per tree) of Kwai May Pink lychee at Mareeba in north Queensland over 4 years. Data are the means of 5 trees per treatment ± s.e. In 1998, and only for this year, the control trees had significantly larger canopies (t-test, $P_{0.05}$) than the pruned trees, which were pruned more severely than in previous years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date of pruning</th>
<th>Pruned trees</th>
<th>Control trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>March 22</td>
<td>2222 ± 269</td>
<td>2354 ± 26</td>
</tr>
<tr>
<td>1996</td>
<td>March 18</td>
<td>1709 ± 265</td>
<td>2616 ± 57</td>
</tr>
<tr>
<td>1997</td>
<td>March 20</td>
<td>0</td>
<td>2380 ± 133</td>
</tr>
<tr>
<td>1998</td>
<td>March 18</td>
<td>1189 ± 426</td>
<td>3237 ± 296</td>
</tr>
</tbody>
</table>

Table 2. Effect of pruning on relative yield (number of fruit per m² of canopy surface area) of Kwai May Pink lychee at Bundaberg in southern Queensland in 1997. Data are the means of 9-10 trees per treatment ± s.e.. The control trees had significantly larger canopies (t-test, $P_{0.05}$) than the pruned trees.

<table>
<thead>
<tr>
<th>Date of pruning</th>
<th>Pruned trees</th>
<th>Control trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 6</td>
<td>18 ± 3</td>
<td>36 ± 5</td>
</tr>
<tr>
<td>February 26</td>
<td>44 ± 2</td>
<td>49 ± 4</td>
</tr>
<tr>
<td>March 26</td>
<td>19 ± 7</td>
<td>45 ± 6</td>
</tr>
</tbody>
</table>

Southern Queensland

In 1995 and 1996, the pruning was not very severe, with the canopy surface area of pruned trees (33.7 ± 4.0 m²) and the controls (39.7 ± 5.1 m²) not significantly different in 1996 (t-test, $P_{0.05}$). Thus, total yields could be directly compared. Yields of the pruned trees were similar to those of the controls (t-tests, $P_{0.05}$), namely 15.8 ± 3.4 kg tree⁻¹ and 19.5 ± 3.3 kg tree⁻¹ in 1995, and 625 ± 182 fruit tree⁻¹ and 828 ± 129 fruit tree⁻¹ in 1996 (equivalent to about 14 and 18 kg tree⁻¹, respectively).

In 1997 with more severe pruning, the control trees had significantly (t-test, $P_{0.05}$) larger canopy surface areas than the pruned trees (32.7 ± 1.8 m² vs. 24.4 ± 1.3 m² for 3 February, 37.7 ± 1.9 m² vs.
28.3 ± 0.8 m$^2$ for 26 February, and 39.6 ± 2.5 m$^2$ vs. 28.7 ± 1.3 m$^2$ for 26 March). Consequently, yields were compared per unit canopy surface area (Table 2). The trees pruned on 3 February and 26 March had lower relative yields than the controls (t-tests, $P_{0.05}$). In contrast, the relative yields of those pruned on 26 February were not significantly different from the controls (t-test, $P_{0.05}$). That the yields of these trees on a canopy surface area basis were similar to the control non-pruned trees indicates that these trees could be pruned annually and planted at close spacings for intensive production.

The critical dates for flush commencement near Bundaberg from the model of Olesen et al. (2000b) are 10 January for median two flushes before winter, 25 February for guaranteed one flush, and 12 March for median one flush out. To achieve these commencement dates, trees would need to be pruned approximately 10 days beforehand. In our experiments near Bundaberg, pruning in either early February or late March resulted in poor cropping, as expected from the model. In contrast, trees pruned around late February gave relative yields comparable to those of the controls in three out of three years. A late February pruning approximately corresponds with the pruning date expected from the model configuration based on one flush out from winter in the median year.

It was noted above, that cropping was unreliable near Mareeba when pruning dates were based on this configuration, and that the best predictions seemed to come from a configuration based on at least one flush before winter. The reason for the discrepancy between the two sites is unclear, although it may relate to local weather conditions, since the kinetics of flush development near Bundaberg were not dissimilar from those on which the model was based (Olesen et al. 2000b).

In north Queensland, fruit are harvested in December, and one can normally expect to be able to prune shortly after harvest and have two vegetative flushes completed by winter. By contrast, near Bundaberg there would seldom be time for the completion of two vegetative flushes following post-harvest pruning.

The control trees near Bundaberg fruited every year. In 1995, there was a fully extended light green flush at the time of pruning on 8 March, and this was the last flush until the trees initiated panicles in winter. In 1996 and 1997, the control trees generally flushed in late February or early March, and had extendedflushes by mid-April. For these two years, this corresponded with pruning in mid- to late February. Overall, pruning in late February is the best recommendation for the Bundaberg area, but the basis of this recommendation is not as strong as that for the Mareeba area.

**Conclusion**

Controlling tree size in lychee orchards is necessary for efficient pest control and harvesting. Olesen et al. (2000b) argued on the basis of a model of lychee flush development that there should be latitudinal variation in the optimum time for pruning along Australia’s eastern seaboard. The results of our experiments support their argument, with the optimum time for pruning trees in northern Queensland being somewhat later in the year than that for southern Queensland. Furthermore, there was sufficient correspondence between our results and the model predictions for the model to be thought to give reasonable first approximations to the most appropriate pruning times. Growers should then experiment with pruning dates around these approximations to establish the best pruning strategy for their location.

Variations in weather conditions from one year to the next mean that no pruning strategy *per se* is likely to be fail-safe. However, the safety factor might be greatly increased if pruning is used in conjunction with other measures to control flush development. For example, a grower might favour a guaranteed completion of one flush by winter in every year, and deal with the occasional tendency for late autumn vegetative flush by using drought, ethephon or tipping (see Chapter 6). The science behind the first of these measures, is as yet, not well understood in Australia.
References


Olesen, T., Menzel, C. M., Batten, D. J., McConchie, C. A. and Jones, P. N. (2000a). Effects of pruning on the flushing cycles and flowering of lychee. *Australian Journal of Botany*


Figure 1. Variations in (A) flowering and (B) yield for Kwai May Pink lychee trees pruned at different times in Mareeba in northern Queensland. Data are presented as the back-transformed means (± s.e.) of 5 trees per treatment. Details of the fitted curves are given in the text.
Figure 2. Relationship between yield and flowering in 1998 in Kwai May Pink lychee at Mareeba in northern Queensland in 1998. Data are for individual trees (n = 40). The fitted curve is $y^{0.5} = 0.012 \times x^{1.46}$ ($r^2 = 0.85$).
Evaluation of Canopy Management by Lychee Growers

Summary

Experimental blocks were set up in the major lychee growing areas of eastern Australia in 1998 to demonstrate the value of canopy management to industry. Trees in commercial orchards were pruned at various times from late January to late March in 1998 at 17 sites stretching from Cairns and Mareeba in northern Queensland to Ballina in northern New South Wales. Cultivars used included Tai So, Fay Zee Siu, Kwai May Pink, Salathiel and Wai Chee. Vegetative growth, flowering and yield were recorded. Overall, flowering was generally best with pruning in early February in northern New South Wales, from mid-February to early March in southern Queensland, and from early to mid-March in northern Queensland. This is in line with previous research in the different districts, and supports the model developed to predict the optimum time for flush development and flowering. The data collected also highlight the difficulty of achieving regular lychee yields in tropical environments, which is related to insufficient chilling for floral induction. The response to pruning and other tree management operations are more difficult to predict in this tropical environment.

Commercial Implications. Canopy management was evaluated by commercial lychee growers across eastern Australia. Trees were pruned at various times after harvest and their growth and performance assessed. Growers were issued with kits to carry out the work on their own farms. This strategy to get growers involved has worked very well, and has heightened the value of canopy management to industry.

Introduction

In this part of the research, demonstration blocks were set up in the major lychee growing areas of eastern Australia. Trees in commercial orchards were pruned at various times from late January to late March in 1998, and vegetative growth, flowering and yield recorded. These experiments demonstrated the value of canopy management to the lychee industry. We were also interested to see whether the optimum times of pruning were in broad agreement with the model developed by Olesen et al. (2000) on the pattern of flushing and flowering of lychee in different environments.

Materials and Methods

Demonstration blocks were set up in the major lychee growing areas of eastern Australia. Trees in commercial orchards were pruned from late January to late March. Cultivars used included Tai So, Fay Zee Siu, Kwai May Pink, Salathiel and Wai Chee. As with the experimental blocks, the grower sites were monitored at regular intervals for stage of flush development (see plate and Table 1), with flowering and yields also recorded. The lychee trees were grown as commercial crops with respect to watering, fertilizing and pest control (Greer 1995).
Table 1. Stages of flush development in lychee (see plate).

<table>
<thead>
<tr>
<th>Stage of flush development</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>Buds not moving; leaves mature and hard green.</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Young buds swollen to a few millimetres in length (the approximate maximum size for buds to respond to florally inductive weather conditions).</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Early flush development, marked by stem and petiole elongation. Mainly unexpanded leaflets.</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Mid-flush development, marked by stem elongation and leaflet expansion.</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Fully extended flush with brown-green or red-green expanded leaflets.</td>
</tr>
<tr>
<td>Stage 6</td>
<td>Hardening off, with soft-green leaflets.</td>
</tr>
</tbody>
</table>

Results and Discussion

A general summary of the various pruning experiments is given in Table 2. In northern Queensland, the best response generally occurred with a pruning before mid March, whereas in southern Queensland and northern New South Wales, optimum times were about 4 to 6 weeks earlier. Flowering was somewhat erratic reflecting the warmer than average winter temperatures. The results highlight the benefit of ethephon applications to restore production in some years.

Table 2. Details of the various grower trials in lychee in eastern Australia in 1998.
Stage 1

Stage 2

Stage 3

Stage 4

Stage 5

Stage 6
Examples of the responses in the different orchards in southern Queensland are provided below.

**Daraglen**

The results for the staggered pruning trial of Kwai May Pink trees at Daraglen farm were in line with what was expected from previous work on pruning times in southern Queensland and in northern New South Wales. Those trees pruned in mid-February and early March put on one vegetative flush before winter, then started a floral flush in winter, which produced very strong flowering in spring (Figure 1). By contrast, those trees pruned in mid-March did not commence a vegetative flush until well into April. This April flush did not harden-off until the spring, and so missed the cold weather needed during early flush development for flower initiation. A late red-green spring vegetative flush covered many of the trees on the field day in October.

**Sippy Orchards**

As expected, Kwai May Pink trees pruned in early February produce two flushes going into winter, while trees pruned in late March had difficulty completing one vegetative flush. Only a few of these trees flowered (Figure 2). In contrast, trees pruned in late February produced one vegetative flush in autumn and flowered, although the flower panicles were very leafy. The initiation of leaf flushing was similar in Wai Chee trees nearby, however, they generally did not flower. This may have been due to the trees receiving insufficient chilling for flower initiation during the warm winter.

**Woombye**

Treatments were similar to those applied at Sippy Orchards, namely, non-pruned controls, and trees pruned in late February, mid-March and late March. All the control trees, and those pruned in late February and mid-March, produced one leaf flush and flowered, while those pruned in late March had red flushes in winter and no flowering in spring (Figure 3).

**Yandina**

Trees of cultivars Kwai May Pink and Salathiel were pruned in early March, while non-pruned trees were used as controls. Both control and pruned trees of Kwai May Pink flushed in March and flowered in August, with little difference between the two treatments (Figure 4). The Salathiel trees that were pruned also produced a flush in March which hardened off by May or June, and flowered in August (Figure 4). The flowering was very leafy, possibly reflecting again the warm winter. In contrast, the controls produced a second leaf flush in May which only matured in August or September. Consequently, these trees did not flower.

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**Figure 1.** Effect of pruning on flowering in Kwai May Pink lychee at Daraglen Farm in 1998. There appears to be no disadvantage for pruning at the right time.

<table>
<thead>
<tr>
<th>Time of pruning</th>
<th>Control</th>
<th>Mid-February</th>
<th>Early March</th>
<th>Mid-March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating of flowering in August (scale 0-9)</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

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44
Figure 2. Effect of pruning on flowering in Kwai May Pink lychee at Sippy Orchards in 1998. Wai Chee had similar leaf flushing, but little flowering.

Figure 3. Effect of pruning on flowering in Kwai May Pink lychee at Woombye in 1998.
Conclusion

Overall, flowering was generally best with pruning in early February in northern New South Wales, from mid-February to early March in southern Queensland, and from early to mid-March in northern Queensland. This is in line with previous research in the different districts, and supports a model developed to estimate the optimum times for flush development and flowering (Olesen et al. 2000). The data collected also highlight the difficulty of achieving regular lychee yields in tropical environments, which is related to insufficient chilling for floral induction (Menzel and Simpson 1988, 1995; Batten and McConchie 1995).

References


The Use of Ethephon and Pruning to Control Winter Flushes in Lychee

Summary

The model of lychee flush development and flowering, can be used to provide estimates of the most propitious dates for pruning in summer or autumn (see above). However, in some years, these times will produce a late autumn flush which is unlikely to flower because they are unlikely to encounter cool weather when they flush again in spring. Hence, we were interested in remedial treatments to control these flushes. This was to see if the pruning treatments could be adjusted because of the unpredictability of the weather. Trees with young red flushes in winter growing at Mareeba, Bundaberg and Childers were pruned or sprayed with ethephon (as 1 to 3 litre of Ethrel plus 5 kg urea per 1000 litre) in May and June, and subsequent flush development, flowering and yield determined. The main cultivar used was Kwai May Pink, although Salathiel and Wai Chee were also included.

In initial experiments, trees that were pruned heavily in May or June (30-50 cm terminal growth removed) flowered just below the pruning cut, but had only had a third of the yield of the controls or trees pruned in March. This was related to the removal of mature leaves that support the developing fruit. In other experiments, trees were pruned in February or March to induce young red leaf flushes in winter. Control trees with red flushes in May and June generally flowered poorly when rated in early August. The best flowering occurred with trees lightly pruned in May or sprayed with ethephon in June. These experiments demonstrate the value of remedial measures if leaf flushes develop in winter. Whether such treatments have application in longan and rambutan is not known.

Commercial Implications. The model of lychee flush development can be used to estimate the optimum date for pruning in different districts. However, in warmer than average years, the trees may produce a late autumn leaf flush which will not flower. Experiments have shown the a light pruning in winter or application of ethephon can selectively remove these flushes and restore cropping. These treatments build on research which developed pruning strategies after harvest to control tree size, and improve the reliability of fruiting in commercial orchards.

Introduction

Irregular bearing is a major problem for the lychee industry in Australia, and in most instances is due to the trees not flowering (Menzel and McConchie, 1998). Flowering only occurs when temperatures fall below 20°C. However, the cold weather is only effective when the new buds of a flush start to swell and are just a few millimetres long. It is ineffective when the new shoots are 10 mm or longer (Batten and McConchie 1995). It follows that buds that begin to grow in winter during cool weather, will flower and crop.

A simple way to manipulate bud development is to tip-prune the shoots. We have developed a model of lychee flush development and flowering, which predicts the optimum dates in summer and autumn for pruning so that the canopy regenerates and flowers (Olesen et al. 2000). In some years, however, trees pruned on these dates will produce late autumn vegetative flushes, because of unusually warm and bright weather conditions, which will have a low chance of flowering. Hence, we examined the effects of late autumn pruning and ethephon sprays on these young flushes. The treatments were applied in May and June, and subsequent flush development, flowering and yield determined. Examples are given for trees growing at Mareeba, Bundaberg and Childers.

Materials and Methods
Experiments in 1995

During 1995, trees of the lychee cultivar Kwai May Pink were tip-pruned at two sites in eastern Australia: Barry Hartley’s farm near Mareeba in north Queensland on March 15 and June 15; and at Electra Farmlands near Bundaberg on March 8 and May 16. On each occasion, four or five trees were pruned and four or five were left as controls. Approximately 40 cm was cut from every branch. At both sites, we measured the extension of the new vegetative shoots and panicles (floral shoots) for eight branches on each tree, at approximately fortnightly intervals. We also recorded the times of flowering and fruit set, and measured yields. The lychee trees were grown as commercial crops, with respect to watering, fertilizing and pest control (Greer 1995).

Experiments in 1998

Standard treatments on the Kwai May Pink trees at Derek Foley’s Bundaberg farm were non-pruned controls, or trees pruned in early February, late February and late March. The late February treatment had young red flushes going into winter, and these were subsequently treated with ethephon in June as 2 litre ethrel and 5 kg urea per 1000 litre. In other experiments at Electra Farmlands, trees of Kwai May Pink were pruned in early February to induce a second young flush in winter. A set of trees was left as untreated controls, while others were lightly tipped in May (pruned) or sprayed with ethephon to remove the immature leaves. There were seven trees in each treatment.

There were also two other trials at Childers (Ivan Philpott and Russ Proudfoot). Trees of Kwai May Pink and Wai Chee were pruned in early March and subsequently produced young red flushes in May. Groups of trees were pruned lightly in June, sprayed with ethephon in June, or left as untreated controls. The effects of the treatments on subsequent leaf growth, flowering and yield were recorded. There were between three and eight trees in each treatment. Ethephon was applied at the rate of 1 to 3 litre of ethrel plus about 5 kg urea per 1000 litre.

Results

Experiments in 1995

Mareeba. The lychees pruned in June flowered well, but produced a poor crop. Yields were only a third of those from the unpruned controls (Table 1). Trees pruned in March produced a new vegetative flush in late March and early April which hardened off by late June. The flush which followed soon after was floral and continued to grow until the flowers opened in mid-September. The pruned trees had a similar yield as the controls, and did so with a 5% reduction in canopy spread.

Bundaberg. Pruning in March produced a vegetative flush soon after which matured before panicles emerged in mid-July. These trees flushed about six weeks later than the controls which had a red-green leaf flush in early March. The yield of the pruned trees was 20% less than that of the non-pruned trees (Table 1). For the May series, the pruned trees only had a third of the yield of the controls, once again related to the removal of mature leaves which support the developing fruit.

<table>
<thead>
<tr>
<th>Date of pruning</th>
<th>Control trees</th>
<th>Pruned trees</th>
</tr>
</thead>
</table>

Table 1. The effect of pruning on the yield (kg per tree) of Kwai May Pink lychee in eastern Australia in 1995.
Experiments in 1998

Bundaberg. As expected, the trees pruned in early February in the experimental Kwai May Pink block initiated two flushes prior to winter, while the trees pruned in late March initiated only one. Both groups carried relatively immature flushes going into winter, and flowering was very poor. The trees pruned in late February produced a second vegetative flush in May or June, in contrast to previous years when trees pruned at such a time flowered on the second flush. The second vegetative flush in 1998 was caused by the unusually warm and fine weather that year. These trees flowered after the application of ethephon (Figure 1).

In the other experiment at Bundaberg, where sets of trees were pruned in early February to provide plots with red flushes in winter, the control trees scored poorly when rated for flowering in August, whereas those that were lightly tipped or sprayed with ethephon flowered (Figure 2).

Childers. Similar experiments were conducted at Ivan Philpott’s farm at Childers, except the trees were pruned in June rather than in May. Ethephon was effective in inducing flowering, whereas the pruning appeared to be too late. Results are shown for Kwai May Pink (Figure 3). Similar data were collected for Wai Chee, although the flower panicles were very leafy due to the warm winter conditions. At Russ Proudfoot’s farm, ethephon was applied to Kwai May Pink and Wai Chee trees, and was shown to control winter shoots and induce flowering. These experiments did not include a mechanical pruning treatment. Similar experiments have been carried out in 1999, and the results appear just as encouraging. There have been no reports of toxicity.

Discussion

The recommendations for pruning after harvest in the different districts are based on long-term weather data, and a model of flush development (Olesen et al. 2000). They represent an historical guarantee of at least one vegetative flush by winter. However, in some years, the weather will be considerably warmer and brighter than the coldest, dullest year, and trees will produce a second flush in late autumn rather than flower.

At the moment, there are broadly two ways to deal with this possibility. Firstly, following the lead of Israeli and some South African growers, trees might be droughted once the post-pruning autumn flush has fully elongated, preventing further flush emergence until the trees are re-irrigated in winter. Such a strategy is clearly only possible in areas with distinct dry periods in winter, and thus is probably only applicable in Mareeba or possibly Bundaberg. There is also a problem in that the degree and timing of the drought have not been defined.

Secondly, the late-autumn flush might be delicately pruned-off, or selectively defoliated chemically, just prior to winter. Both courses of action promote a winter flush soon afterwards. The chemical option is more convenient than the pruning one, but the testing of defoliants is still only at the experimental stage, and the main defoliant that we are dealing with, ethephon, is not yet registered for lychee. With the pruning option, care must be taken not to remove the leaves of the mature flush behind the late autumn flush, as this will tend to reduce yields.
Either the pruning, or the defoliation of late autumn flushes with ethephon, increased flowering with respect to the non-treated control trees in experiments at Bundaberg. These remedial measures can also be used to correct the flushing patterns of trees that have not been pruned in the current season. Generally, cropping was greater with pruning in March than in May or June, reflecting the need for a leafy canopy to support the developing crop.

References


Figure 1. Effect of pruning and ethephon application in June on flowering of Kwai May Pink lychee at Electra Farmlands in 1998. Trees were pruned in early February, pruned in late February/sprayed with ethephon in June or pruned in late March.

Figure 2. Effect of manual tipping in May and ethephon application in June on flowering of Kwai May Pink lychee at Electra Farmlands in 1998.
Figure 3. Effect of manual tipping and ethephon application in June on flowering of Kwai May Pink lychee at Ivan Philpott’s near Childers in 1998.
The Relationship Between Productivity and Tree Structure in Lychee

Summary

Productivity in tree crops, such as lychee, is driven by the amount of light intercepted by the canopy. Leaves can be harvested and total leaf area per tree calculated, but this is very time-consuming and expensive. We investigated two non-destructive methods of measuring leaf area in this species. Five mature trees of Kwai May Pink lychee growing at Alstonville in northern New South Wales were stripped of their leaves over three days, and actual leaf area per tree compared with estimates from the DEMON Leaf Area Instrument (CSIRO, Australia) and the LAI-2000 Plant Canopy Analyser (LI-COR, USA). Both these instruments use the amount of light intercepted by the canopy to estimate leaf area index. The DEMON estimated 68% of actual leaf area (explained variance 89%) based on the formula of Lang (1986), compared with the LAI-2000 which estimated 11% of actual leaf area (explained variance 68%).

Although both instruments underestimated actual leaf area, the discrepancies were such that simple correction factors might be applied. The DEMON gave the better estimate and discrimination (higher explained variance), however, the LAI-2000 was easier to use. It is possible that the operation and accuracy of the LAI-2000 could be improved.

In another experiment, ten trees of the cultivar Kwai May Pink growing in a commercial orchard near Bundaberg were chosen for a study of the changes in lychee yield and leaf area production that occur as trees become larger. Trees ranged from six to nine years of age, with at least 0.5 m between adjacent trees. Information was collected on the total number of leaves on each tree, total leaf area, specific leaf area (dry weight per unit leaf area), canopy surface area, and yields measured at harvest.

Canopy surface area per tree varied from 24 to 53 m²; total number of leaves from 2700 to 9200; and total leaf area from 11 to 40 m². Relative leaf area index, that is, the ratio of leaf area to canopy surface area, varied from 0.48 to 0.83 and was essentially independent of tree size. Relative yields were 19.2 ± 1.6 of fruit per m² of canopy surface area, or 30.7 ± 2.6 of fruit per m² of leaf area across the various trees, and not correlated with canopy surface area. In other words, fruit production was simply dependent on the total bearing surface of the trees, so that large trees were not more efficient (fruit per unit leaf area) in producing fruit than small trees. With an individual leaf having an area of 45.7 ± 1.8 cm² across the various trees, it follows that about seven leaves were required to fill each fruit. The specific leaf weights of the most recent vegetative flush were 125 ± 2 g m⁻² across the various trees, with no obvious effect of tree size. These results highlight the productivity of small trees planted at close spacings.

There was no apparent trend in the variation in relative yield over a 3.4-fold range of canopy surface areas consistent with the trees being in the full sun for most of the day. There was also no apparent trend in relative yield with relative leaf area index, indicating that a higher value conferred little additional productive benefit. It may be that many mature lychee trees have a considerable number of leaves which contribute little to overall productivity.

Experiments were conducted on Kwai May Pink trees growing at Bundaberg to determine the relationship between fruit size and crop load as affected by pruning. This followed other experiments where the size of the canopy supporting the developing crop was altered by pruning after harvest. Trees were pruned in early February, late February or late March, while other trees were not pruned, and used as controls. Pruning involved the removal of about 1 m from each terminal branch, and some internal thinning of branches as well. A record was kept of canopy surface area, light interception, yield and average fruit size in the different treatments.
At harvest, the average canopy surface area of the pruned trees was 26% smaller than the control trees. Pruning in late February resulted in a two-fold rise in diffuse non-interceptivity (fraction of radiation <490 nm transmitted through the canopy) compared with the controls, related to a single leaf flush between pruning and harvest in this treatment. The trees pruned in late February had two-thirds the number of fruit of the controls, and similar yields when fruiting was expressed on a canopy surface area basis. In contrast, the yields of the trees pruned in early February and late March were much lower reflecting poor flowering. In other words, severe pruning had little effect on the capacity of remaining branches to bear fruit, provided there was time for partial canopy renewal and good flowering.

The fruit of the trees pruned in late February were larger than the fruit from the other groups. There was a possible interaction between the timing of initial fruit set and fruit density, which resulted in a mid-range peak in fruit size when expressed against relative yield. At relative yields higher than 40 fruit m\(^{-2}\), fruit were probably smaller because of increasing competition for limited resources. The decline in fruit size below 40 fruit m\(^{-2}\) might have been related to late fruit set. The variation in the size of the fruit at harvest had little effect on the relative proportions of seed, aril and pericarp. Variations in weather conditions from one year to the next, and the effects these have on plant development and phenology, mean that pruning \textit{per se} can not be timed to improve fruit quality. A better approach is to irrigate and fertilize the trees or prune them to improve light distribution to maximize carbon production by the leaves. This is separate to the issue of flower initiation.

**Commercial Implications.** A non-destructive method was developed to estimate leaf area in lychee trees. This method can be used in future research to examine the relationship between yield and leaf area in lychee, under different pruning regimes. Direct measurements of leaf area in tree crops are very expensive. In other experiments, fruit production was shown to be dependent on the total bearing surface of the trees, so that large trees were not more efficient in producing fruit than small trees. These results indicate that small trees planted at close spacings will be just as productive as large trees planted at wide spacings. They will also make efficient use of land in the first few years after planting, and will be easier to harvest, spray and net. Overall returns to growers will be greater with this system.

**Introduction**

Plant production depends on the conversion of sunlight into chemical energy, and, for the most part, this process takes place in the leaves. Consequently, models of plant productivity commonly include some measure of leaf area (e.g. Génard \textit{et al.} 1998 in peach).

There has been a strong move to improve the productivity of temperate fruit trees in the past 30 years or so, based on an understanding of the relationship between yield and light interception. Modern apple and stonefruit orchards are planted at high density and trees kept small through the use of dwarfing rootstocks and intensive pruning. These systems maximise the interception of light by the canopy (Clayton-Greene 1993; Wagenmakers and Callesen, 1995; and Campbell \textit{et al.} 1996). This philosophy is not well developed in tropical fruit trees (apart from citrus), with few dwarfing rootstocks or validated pruning strategies.

Lychee trees generally set many more fruit than they can carry to harvest (Menzel \textit{et al.} 1999). One can remove half of the potential crop or more at flowering and still obtain a heavy crop, usually 70 to 90% of the yield of control unpruned trees. On the other hand, removing part of the canopy can dramatically affect production. Yield can be reduced by half when the leaves of the last flush or the flush before are removed, and reduced by about 30% if older leaves are removed. In general, trees probably have enough potential fruiting terminals for good production, but there may be insufficient
leaf area. These results are supported by the winter pruning treatments which were very effective in inducing flowering, but only had about 30% of the crop of control trees (see Chapter 6).

There have been very few direct measurements of leaf area in tree crops, largely because of the prohibitive amount of work involved. A mature lychee tree, for example, typically has tens of thousands of leaves. The common expedient is to calibrate the actual leaf area of a few representative trees with some measure of radiation transmission through the canopy, one that is variably transformed into a putative estimate of leaf area. A similar approach is employed here. Two indirect methods for estimating leaf area in mature lychee trees growing in northern New South Wales were compared: the DEMON Leaf Area Instrument (CSIRO, Australia) and the LAI-2000 Plant Canopy Analyser (LI-COR, USA). Values estimated from these two instruments were correlated with leaf area calculated from destructive harvests.

In previous research with other species, DEMON and LAI-2000 estimates have invariably been correlated with actual values, sometimes with close to a 1:1 correspondence, but often under-estimating or, less commonly, over-estimating total leaf area by 10% or more (Welles and Cohen 1996). In the subtropical horticultural context, the LAI-2000 under-estimated the leaf area of macadamia, *Macadamia integrifolia* by 30 to 56% (Noel Meyers *et al.* personal communication), but only by 7% in olive, *Olea europaea* (Villalobos *et al.* 1995). For grape-vine, *Vitis vinifera* the DEMON gave estimates very close to actual values, while the LAI-2000 under-estimated leaf area by 15% using one method and by 60% using another (Sommer and Lang 1994).

Lychee is generally propagated by marcotting, with the trees taking four to five years to come into commercial production. Once they begin bearing, they can yield for a very long time, with a 1200-year-old tree still productive in a Chinese orchard (Sang 1980). Many old orchards in Australia were planted at spacings of 9 or 10 m x 12 m or even 12 m x 12 m, equivalent to about 70 to 80 trees per ha. Such plantings can have very high yields on a tree basis after 10 or 15 years, but are wasteful of land in the early years. There are also problems with harvesting, spraying and protection from birds and bats in large trees. Newer orchards are planted at closer spacings of 6 m x 8 m or 4 m x 6 m or 7 m x 3 m, equivalent to 200 to 460 trees per ha (Menzel and McConchie 1998). These orchards require regular pruning to keep the trees small. There are high-density plantings up to 1200 trees per ha in southern China, but these are dependent on hand spraying (Zhang *et al.* 1997).

The economics of high-density plantings in Australia have yet to be analysed. Whether the higher yields per unit land area initially, and the lower growing costs later, outweigh the higher establishment costs and the lower yields per tree later is not known. It is also not known whether yield is related to total leaf area per ha, so that a few large trees would be expected to be as productive as many small trees. There is also probably no advantage in very close plantings where the trees start to crowd each other before they begin to bear at year four or five. Here we report on the relationship between yield and tree size for a group of ten small trees growing in an orchard near Bundaberg. This was to test whether larger trees were more productive per unit leaf area. There has been no previous study on allometric growth in lychee.

The timing of pruning affects the phase of the flushing cycle in lychee and, consequently, the extent to which trees flower and bear fruit (Chapters 2, 3 and 4). Crop load is known to affect fruit size in apple, with very high-yielding trees often having small fruit (e.g. Palmer 1992; Volz *et al.* 1993; Schechter *et al.* 1994; Palmer *et al.* 1997). We thus chose to study the relationship between fruit weight and cropping as influenced by pruning. Kwai May Pink trees growing at Bundaberg were pruned in early February, late February and late March, and a record kept of canopy surface area, light interception, yield and average fruit size. The only previous work on the effects of crop load on fruit size in lychee was that by Roe *et al.* (1997), who varied fruit number on girdled branches, and found a trend for an increase in fruit size with decreasing number of fruit.

**Materials and Methods**

Materials and Methods
Comparison of the DEMON and LAI-2000 Canopy Analyser

Five trees of the lychee cultivar Kwai May Pink growing at the Tropical Fruit Research Station, Alstonville, in northern New South Wales were gradually stripped of their leaves over three days in April 1996. By the end of the experiment, there were no leaves remaining on the trees.

Prior to the first leaf-stripping, total plant light interception measurements were made with both the DEMON and the LAI-2000. The DEMON measurements involved the pegging of a quadrat which contained the shadow of a given tree, followed by the tracking of the sun with the instrument sensor as evenly as possible across the area of the quadrat. The procedure was repeated at least four times, and consequently there were at least four solar altitudes for each tree. The LAI-2000 measurements were made at the end of the day when the last of the direct sunlight had left the orchard. The instrument sensor was limited to a 90° azimuthal field of view. Measurements were taken near the trunk at the base of the canopy. Four measurements were made for each tree, in each of four quadrants. Reference measurements were made above the canopy from a cherry-picker. Similar DEMON and LAI-2000 measurements were made after each leaf-stripping. Estimates were made of total leaf area per tree from the DEMON measurements, and leaf area density from the LAI-2000.

The leaves from each tree were bulked, dried at 65°C and weighed. Leaf areas were calculated as the product of the dry weight and the leaf area to dry weight ratio estimated from a sample of 30 leaves from five trees. The total leaf area on a tree at any given time was calculated by summing back from the last leaf-stripping.

The height and width of the canopy of each tree was measured, and canopy surface area and canopy volume calculated assuming that the canopy shape was an oblate or prolate ellipsoid, with width having the circular cross-section. The surface area of a prolate ellipsoid is:

\[ 2\pi b H \{ \sin^{-1} \left( \frac{a}{H} \right) + a \left( \frac{H^2 - a^2}{H^2} \right)^{0.5} \} \]

where,
\[ a = \text{radius of axis about which the ellipse is rotated} \]
\[ b = \text{radius of perpendicular axis} \]
\[ a > b \]
\[ H = \left\{ \frac{a^4}{(a^2 - b^2)} \right\}^{0.5} \]

The surface area of the oblate ellipsoid is:

\[ 2\pi b K \{ \sinh^{-1} \left( \frac{a}{K} \right) + a \left( \frac{K^2 + a^2}{K^2} \right)^{0.5} \} \]

where,
\[ a < b \]
\[ K = \left\{ \frac{a^4}{(b^2 - a^2)} \right\}^{0.5} \]

(\text{Smith 1966})

From these calculations it was possible to convert the destructive harvest and DEMON estimates of total leaf area, and the LAI-2000 estimates of leaf area density, into leaf area per canopy surface area.

Allometric growth in lychee trees at Bundaberg

Ten trees of the lychee cultivar Kwai May Pink growing in a commercial orchard near Bundaberg (25°S 152°E) were chosen for the study. Trees ranged from six to nine years of age, and all had a new red flush commencing in March, 1996. The inter-canopy distance with the nearest neighbour was at least 0.5 m. In July, 1996, the total number of leaves on each tree was counted. At harvest, yields were measured as total number of fruit. After harvest, twenty healthy, intact leaves from the
most recent vegetative flush of each tree were collected for the determination of specific leaf weights (dry weight per unit leaf area); while samples of 122 to 530 leaves were collected for the determination of average leaf area. At the same time, the heights and widths of the canopies were measured, from which measurements of canopy surface areas were calculated by assuming that canopy shape approximated half an oblate or prolate ellipsoid.

**Relationship between fruit size and yield in pruned trees**

Twenty Kwai May Pink lychee trees were selected near Bundaberg in southern Queensland, on February 3, 1997, and evenly divided into two groups, one of which was pruned, the other left as a control. The procedure was repeated on February 26 and March 26, with 20 and 18 trees, respectively. Pruning involved the removal of about 1 m from the entire canopy surface of the tree, and some internal thinning of branches as well. Four branches were tagged on each tree in an arc from north-west to north-east.

The trees were monitored for flowering from September, and scored for the number of branches producing panicles in October, on a ranking of 1 to 10. On November 13, the tagged branches were scored for the number of fruit per panicle. At the same time, measurements were made of the diffuse non-interceptivity of the canopies using the LAI-2000 Canopy Analyser (LI-COR, U.S.A.). Diffuse non-interceptivity is the fraction of radiation <490 nm transmitted through the canopy onto a horizontal surface. For each measurement, the sensor was located at the base and centre of the canopy.

At harvest, on December 31, the tagged branches were again scored for the number of fruit per panicle; the largest fruit from the four branches was weighed for its total fresh weight, then weighed again for the fresh weights of the seed, aril and pericarp. Counts were made of the number of fruit per tree; and the heights, breadths and widths of the canopies were measured for calculation of surface areas, assuming that the measurements represented the lengths of the axes of irregular ellipsoids, and that the overall canopy shapes were the shells of half such ellipsoids (see Chapter 4).

**Results**

**Comparison of the DEMON and LAI-2000 Canopy Analyser**

The leaf harvests were used as the reference against which to compare the estimates from the DEMON and the LAI-2000. The DEMON estimates of relative leaf area based on the formula of Lang (1986), were 68% those of actual leaf area (Figure 1; explained variance 89%); while those based on the formula of Lang (1987) were 64% (data not shown; explained variance 89%). The LAI-2000 estimated 11% of actual leaf area (Figure 1; explained variance 68%).

The way in which to use the DEMON is largely prescribed. With the LAI-2000, however, there is much more discretion open to the operator. It may have been, then, that the apparent poor estimates by the LAI-2000 were related to the way the instrument was employed.

A higher estimate of relative leaf area was obtained with the LAI-2000 when the output was analysed non-conventionally: by only using the output from the 47-58° zenith angle sensor; by assuming that the foliage projection fraction in this angular band was approximately 0.5 (Lang 1987); and by assuming that the relative leaf area in the band was representative of the whole tree. By these assumptions:

\[
\text{relative leaf area} = -2 \sin \alpha \ln T
\]

where, \(\alpha\) = the acute angle made by the view elevation of the sensor and the tangent of the edge of the canopy.
The relative leaf area estimated in this way was 26% of actual values (explained variance 60%).

The LAI-2000 also calculates a ‘diffuse non-interceptance’ factor (d), the fraction of radiation (<490 nm) transmitted through the canopy onto a horizontal surface. This was inversely related to actual values (\(\{1 – d\}^2 = 0.03 \times x^2\); explained variance 68%).

**Allometric growth in lychee trees at Bundaberg**

The values calculated for each of the ten trees at Bundaberg are shown in Table 1. Canopy surface area per tree varied from 24 to 54 m²; total number of leaves from 2700 to 9200; and total leaf area from 11 to 41 m². There was a linear relationship between leaf area and canopy surface area, not significantly different from a straight line passing through the origin (leaf area) = 0.67*(canopy surface area); F-test \(P_{0.05}\), explained variance 68%. This means that the relative leaf area index, that is, the ratio of leaf area to canopy surface area, was essentially independent of tree size (Figure 2).

The relative leaf area index varied from 0.48 to 0.83, and this variation had no apparent effect on relative yield in that the two variables were not significantly correlated (Pearson \(P_{0.05}\)).

Nor were the relative yields correlated with canopy surface area, consistent with no effect of tree size on unit canopy production. The relative yield was 19.2 ± 1.6 of fruit per m² of canopy surface area.

Yields might alternatively be expressed per unit leaf area. As such, the yield was 30.7 ± 2.6 of fruit per m² of leaf area, with no obvious effect of tree size (Pearson \(P_{0.05}\)). With an individual leaf area of 45.7 ± 1.8 cm², calculated from the means for the ten trees, it follows that about seven leaves were required to fill each fruit.

The specific leaf weight of the most recent vegetative flush was 125 ± 2 g m⁻², with no obvious effect of tree size (Pearson \(P_{0.05}\)). Specific leaf weight is a marker for differences in the ambient environment, in that it tends to decline with increasing shade, and also varies in response to other environmental factors (Olesen 1994). As a marker, it is not unequivocal, but gives an indication that there were no major size-related environmental gradients, which is to say that the trees of different sizes were growing under similar conditions. The relationship between leaf area and leaf dry weight for mature leaves taken from the most recent vegetative flush is shown in Figure 3.
Table 1. Range in number of leaves per tree, total leaf area per tree, canopy surface area, relative leaf area index (RLAI), specific leaf weight (SLW) and yield for the ten trees at Bundaberg in 1996.

<table>
<thead>
<tr>
<th>Tree</th>
<th>No. leaves per tree</th>
<th>Total leaf area (m² tree⁻¹)</th>
<th>Canopy surface area (m² tree⁻¹)</th>
<th>RLAI (g m⁻²)</th>
<th>SLW (g m⁻²)</th>
<th>No. fruit per tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>2730</td>
<td>11.8</td>
<td>23.6</td>
<td>0.50</td>
<td>120</td>
<td>474</td>
</tr>
<tr>
<td>Two</td>
<td>3135</td>
<td>15.3</td>
<td>31.7</td>
<td>0.48</td>
<td>134</td>
<td>558</td>
</tr>
<tr>
<td>Three</td>
<td>3453</td>
<td>15.4</td>
<td>32.0</td>
<td>0.48</td>
<td>125</td>
<td>563</td>
</tr>
<tr>
<td>Four</td>
<td>4021</td>
<td>20.5</td>
<td>31.3</td>
<td>0.66</td>
<td>113</td>
<td>252</td>
</tr>
<tr>
<td>Five</td>
<td>4603</td>
<td>18.7</td>
<td>33.3</td>
<td>0.56</td>
<td>121</td>
<td>518</td>
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<tr>
<td>Six</td>
<td>4753</td>
<td>20.9</td>
<td>28.9</td>
<td>0.72</td>
<td>135</td>
<td>635</td>
</tr>
<tr>
<td>Seven</td>
<td>6168</td>
<td>25.6</td>
<td>33.1</td>
<td>0.77</td>
<td>135</td>
<td>712</td>
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<tr>
<td>Eight</td>
<td>6784</td>
<td>38.6</td>
<td>51.1</td>
<td>0.76</td>
<td>123</td>
<td>956</td>
</tr>
<tr>
<td>Nine</td>
<td>8227</td>
<td>40.4</td>
<td>48.4</td>
<td>0.83</td>
<td>110</td>
<td>1321</td>
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<td>9138</td>
<td>33.6</td>
<td>53.2</td>
<td>0.63</td>
<td>134</td>
<td>1274</td>
</tr>
</tbody>
</table>

Relationship between fruit size and yield in pruned trees

Effects of pruning on production. At harvest, the pruned trees had significantly smaller canopies than the controls (Table 2). Overall, pruning reduced the canopy surface area by 26%. For the trees pruned in late February, the reduction resulted in a two-fold rise in diffuse non-interceptivity, but the values for the other two pruning treatments were not significantly different from the controls (Table 2). The differences between the pruning treatments in this regard is probably related to the lower number of vegetative flushes achieved by the trees pruned in late February compared with those trees pruned at other times (see below).

The trees pruned in early February and late March had lower yields than the controls, while the yields of those trees pruned in late February were similar to those of the controls (Table 2). As explained in Chapter 4, the reason for this was because of the effect of pruning on the flushing cycles. Those trees pruned in early February flushed in late summer, late autumn and early spring, and flowered poorly (30% of branches flowered in spring, while 70% flushed vegetatively). Similarly, those trees pruned in late March flushed in late autumn and early spring, and also flowered poorly (10%). By contrast, trees pruned in late February flushed in early autumn and in winter, and flowered (100% of branches flowering, similar to the control trees with 90% flowering).

The yields of the trees pruned in late February were similar to those of the controls, when fruit production was expressed on a canopy surface area basis. Thus, severe pruning had little effect on the capacity of the remaining branches to bear fruit, provided there was time for partial canopy renewal. The absolute yields of the pruned trees were, however, lower than those of the controls, owing to their smaller size (Table 2).
Table 2. Tree structure and yield characteristics for pruned and non-pruned control trees. The trials were established in early February (EF, n = 10), late February (LF, n = 10) and late March (M, n = 9, except for the pruned fruit size and pruned fruit per panicle, where n = 8). Diffuse non-interceptivity is the fraction of radiation <490 nm that penetrates to a horizontal surface at the base and centre of the canopy. Fruit size was estimated from the largest fruit on four tagged branches per tree. The number of fruit per panicle was estimated from that panicle on the four tagged branches with the greatest number of fruit.

The superscripts a and b signify control means which were not significant from each other based on ANOVA and the pairwise Tukey test (P_{0.05}). The superscript * signifies a significant difference from the respective control on the basis of either a t-test or rank sum test (P_{0.05}). It also signifies a significant difference from the pooled control mean where there were no significant differences between the control means. The superscript † signifies no significant difference from the respective control (t-test, P_{0.05}), but a significant difference from the pooled control mean (t-test, P_{0.05}). Maximum standard errors of the treatment means also shown.

<table>
<thead>
<tr>
<th></th>
<th>Canopy surface area (m²)</th>
<th>Diffuse non-interceptivity</th>
<th>No. of fruit per m² of canopy surface area</th>
<th>No. of fruit per tree</th>
<th>Fruit fresh weight (g)</th>
<th>No. of fruit per panicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Feb. control</td>
<td>32.7ᵃ 0.11ᵃ</td>
<td>35.5ᵃ 1165ᵃ 14.4ᵃ 7.6ᵃ</td>
<td></td>
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<tr>
<td>Late Feb. control</td>
<td>37.7ᵃ 0.08ᵇ</td>
<td>48.7ᵇ 1827ᵇ 15.0ᵇ 7.5ᵃ</td>
<td></td>
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<tr>
<td>Late March control</td>
<td>39.6ᵇ 0.11ᵇ</td>
<td>44.9ᵇ 1782ᵇ 16.2ᵇ 6.7ᵃ</td>
<td></td>
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</tr>
<tr>
<td>Early Feb. pruned</td>
<td>24.4* 0.10</td>
<td>17.7* 457* 15.7 3.4*</td>
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<tr>
<td>Late Feb. pruned</td>
<td>28.3* 0.17*</td>
<td>43.9 1233* 19.2* 5.2</td>
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<tr>
<td>Late March pruned</td>
<td>27.8* 0.14</td>
<td>18.7* 524* 14.9 3.6†</td>
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<tr>
<td>Max. s.e.</td>
<td>2.1 0.02</td>
<td>6.5 193 0.9 1.7</td>
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</tbody>
</table>

Variations in fruit size. Relative yields were expressed with respect to the number of fruit, but there were significant differences in fruit size as well. In particular, the fruit of the trees pruned in late February were larger than those from the other groups (Table 2). There are several factors that might be involved here. Firstly, there were differences in flowering time, with the control trees flowering first, the trees pruned in late February flowering next and the trees pruned at other time flowering last (Rank sum test, P_{0.05}). Secondly, there was a similar ranking with respect to panicle size, with the earliest flowering trees having the largest panicles (Rank sum test, P_{0.05}), a similar result to that for the 1995 pruning trial in the same orchard (Chapter 2). Thirdly, larger panicles had larger initial fruit set (Rank sum test, P_{0.05}) which carried through to larger fruit clusters at harvest (Table 2), consistent with the fruit thinning experiments by Roe et al. (1997). Fourthly, fruit drop was large for all treatments, as it invariably is for lychee (Roe et al. 1997; Menzel and Simpson 1992), with an overall fruit drop of 67% from November 13 to December 31.

Broadly, there seemed to be an interaction between the timing of initial fruit set and fruit density, which resulted in a mid-range peak in fruit size when expressed against relative yield (Figure 4). At relative yields increasingly greater than 40 fruit m⁻², fruit were smaller because of increasing competition for limited resources. The decline in fruit size below 40 fruit m⁻² may have been related to late fruit set, and fruit developing during warm weather (Kumcha 1999).

When the relative yields of the trees pruned in late February were corrected for fruit size, they were still not significantly different from the relative yields of the late February control trees (t-test, P_{0.05}).
However, the corrected absolute yields of the pruned trees were 87% of the control trees, and also not significantly different (t-test, $P_{0.05}$).

Across all treatments, the variation in the size of the fruit at harvest had little effect on the relative proportions of seed, aril and pericarp (Figure 5). However, this should not be construed as a generalization, as the relative partitioning between the different parts of lychee fruit changes with temperature and water supply (Kumcha 1999).

**Discussion**

*Determining leaf area in lychee*

The destructive harvest was the most labor-intensive and time-costly method for measuring the leaf area of the trees, and was limited mostly by how representative the subsample of leaves used to estimate the leaf area to dry weight ratio was, of all the leaves on a given tree. Although the DEMON and the LAI-2000 both gave lower estimates, the discrepancies were such that simple correction factors might be applied. Of the two instruments, the DEMON gave the better estimate and the better discrimination (higher explained variance) of the rankings, however, the LAI-2000 is easier to use. There is also the suggestion that the operational use of the LAI 2000 could be improved.

The leaf areas calculated by the DEMON and the LAI-2000 are essentially based on extinction coefficients. Wang *et al.* (1991) found that dry matter production in Sitka spruce, *Picea sitchensis* was proportional to the amount of photosynthetically active radiation absorbed. It may be, then, that the calculation of leaf area is an unnecessary intermediate step in the development of predictive production models, and that extinction coefficients other than those used to calculate leaf area, such as the ‘diffuse non-interception’ calculated by the LAI-2000, might be used instead.

*Allometric growth in lychee*

There was no apparent trend in the variation in relative yield over a 3.4-fold range of canopy surface areas. This is consistent with the trees being small and widely-spaced, such that there were only minor differences in the degree of self-shading and shading from other trees, and with there being similar relative partitioning of resources within the plants. It would appear, therefore, that from early in an orchard’s life, fruit production is simply a function of the effective canopy surface area.

Nor was there an apparent trend in relative yield with relative leaf area index. However, the standard error was quite large, with a deviation of $\pm 3.6$ fruit per m$^2$ of canopy surface area from the actual mean being required for significance. This is equivalent to $\pm 19\%$, while the highest value of the relative leaf area index was only 66% greater than the lowest. Even so, it may have been that a higher index value conferred little additional productive benefit. Given that the highest index value in this experiment was only 14% of the highest recorded in the first experiment, it might be that many mature lychee trees have a considerable number of leaves which contribute little to overall productivity.

For Kwai May Pink, there was about seven leaves per harvested fruit. This compares with two to three for Tai So and one to two for Souey Tung (Roe *et al.* 1997). However, these two experiments are not directly comparable. We used whole trees, whereas the previous estimates were based on cinctured branches, where assimilates are sequestered in the branch and do not contribute to the rest of the tree. The leaves of Kwai May Pink are also smaller than those of Tai So.

*Relationship between fruit size and yield in pruned trees*

Variations in weather conditions from one year to the next, and the effects these have on plant development and phenology, mean that pruning *per se* can not be timed to improve fruit quality. A better approach is to irrigate and fertilize the trees to maximize carbon production by the leaves.
References


Figure 1. Relationships between actual leaf area per canopy surface area and leaf area predicted by the DEMON Leaf Area Instrument (closed symbols and $y = 0.68 \times x$) and the LAI 2000 Plant Canopy Analyser (open symbols and $y^{0.1} = (0.11 \times x)^{0.1}$). The 1:1 line also shown. Data collected from five Kwai May Pink lychee trees stripped of their leaves over three days in April 1996 at Alstonville in northern New South Wales. By the end of the experiment, there were no leaves left on the trees.
Figure 2. Variation in tree size with respect to leaf area and canopy surface area \((y = 0.67x)\) in Kwai May Pink lychee at Bundaberg in southern Queensland.

Figure 3. Variation in leaf area and leaf dry weight for mature leaves taken from the most recent vegetative flush \((y^{0.5} = (81.5x)^{0.5}\), explained variance 94%, \(n = 200\)) in Kwai May Pink lychee at Bundaberg in southern Queensland.
Figure 4. Variation in fruit weight with fruit density in Kwai May Pink lychee at Bundaberg in southern Queensland. The fitted lines are of the general form $y = a * b * e^{b*(c-x)} * (1 + e^{b*(c-x)})^{-2}$, that is, the first derivative of the symmetric logistic equation. For the pruned trees (open circle), the sample size was 28; $a = 2295$, $b = 0.032$ and $c = 39.9$; and the explained variance was 42%. For the control trees (closed circle), the sample size was 29; $a = 1792$, $b = 0.036$ and $c = 42.3$; and the explained variance was 20%. Both regressions were significant (F-test, $P_{0.05}$), but the two curves were not significantly different in the heights ($a * b$) or locations ($c$) of the peaks (Tukey-Kramer, $P_{0.05}$).

Figure 5. Variations in the fresh weights of seed (triangle), aril (circle) and pericarp (diamond) with respect to fruit size in Kwai May Pink lychee at Bundaberg in southern Queensland. Open symbols represent fruit from pruned trees ($n = 28$), closed symbols from control trees ($n = 29$). Regressions were of the form $y = a * x$. Those for the pruned trees were not significantly different from those for the control trees (Tukey-Kramer, $P_{0.05}$), and only the regressions for the pooled data sets are shown. Seeds were 13.3% of fresh weight (explained variance 32%); aril 69.4% (explained variance 85%); and pericarp 17.3% (explained variance 61%).
Effects of Irradiation and Temperature on Longan Flush Development

Summary

The recurrent flushing patterns of well-watered, well-fertilised Kohala and Chompoo longan trees were studied at Nambour in southern Queensland (lat. 27°S) using a field-based pruning trial. On seven occasions from November 10, 1997 through to January 30, 1998, one tree of each of the cultivars was pruned, and shoot elongation over time determined along with solar radiation and temperature. The flush commencement dates were estimated as the dates on which shoot elongation was first observed. The flush interval is the number of days between successive commencement dates. Staggered pruning resulted in staggered flush emergence, and this stagger was perpetuated through successive vegetative flushes over 18 months.

The intervals between successive flushes was strongly related to the irradiation and temperature, with the explained variance of the various regressions ranging from 75 to 83%. The flushing rate (the reciprocal of the time between the emergence of successive flushes) was also strongly related to daily irradiation*temperature, with the explained variance of the regressions ranging from 76 to 88%. There were also trends in flowering against pruning date, which followed sinusoidal patterns (probability = 11%), with the estimated periods of the curves (53 days for Kohala and 42 days for Chompoo) close to the flushing intervals expected for late spring through to mid-summer.

The results for longan were broadly consistent with those for lychee. Longan may have a shorter minimum cycle of about seven weeks compared with eight to nine weeks for lychee, and slower growth during cool weather. With further data collection, a model could be developed and applied to long-term weather records from across the geographic range over which longan is grown, to illustrate the latitudinal variation in flush development, as shown for lychee. This could be then used to estimate the optimum time of pruning in different locations. Results from preliminary experiments with mature trees near Mareeba on the Atherton Tableland suggest that pruning of longan in northern Queensland should be carried out as soon as possible after harvest. In southern districts, pruning a proportion of the tree at flowering may be a better option.

Commercial Implications. A model was developed to predict the flushing patterns of longan in different environments. With further work, this model could be used to predict the optimum time of pruning in different districts. Preliminary work in northern Queensland, suggests that longan trees should be pruned as soon as possible after harvest. No specific recommendations can be give for other districts.

Introduction

The longan is a member of the Sapindaceae which includes the related lychee and rambutan. Longan is more closely related to lychee, and crops best in subtropical climates or at elevation in the tropics. It normally flowers and fruits one to two months later than lychee in a given environment. It is very popular in China, Vietnam and Thailand with total production of about 500,000 t, but is not widely grown elsewhere (Menzel et al. 1990). In Australia, most of the orchards are in northern Queensland, particularly on the Atherton Tableland, although there are trees in central and southern Queensland, and in northern New South Wales (Menzel and McConchie 1998). Total production is between 100 to 400 t, depending on seasonal conditions. Longan is very susceptible to biennial bearing, even in warm areas, because the fruit are harvested much later than lychee. There is therefore, less opportunity for the trees to complete a flush before flowering in winter. However, once trees flower
and set fruit, yields are generally very heavy. Trees can grow to more than 10 m, making harvesting, spraying and netting for birds and bats difficult.

Longan is similar to lychee in that it grows by repeated flushes (Olesen et al. 1996) and requires cool weather during early flush development for floral induction to occur (Nopodol Jarassamrit, unpublished data). Consequently, canopy management can be used to control tree height, flushing and flowering. However, a fundamental understanding of the variations in rates of vegetative flush development is needed in the first instance. This could be used to estimate the optimum time for pruning in different environments. Here, we record some of the variation in vegetative flush development at Nambour in southern Queensland (lat. 27°S), and relate this to variations in the prevailing weather conditions. The work is not on the scale of our previous work into the flushing patterns of lychee (Olesen et al. 2000), but clearly indicates that comparable modeling is warranted.

Materials and Methods

On seven occasions from November 10, 1997 through to January 30, 1998, one tree of each of the two longan cultivars Kohala and Chompoo was pruned at the Maroochy Research Station, Nambour (27°S 153°E), giving a total of seven pruned trees for each cultivar. Pruning involved removing between 0.5 to 1.0 m from each terminal branch around the tree. Following pruning, the elongation of eight branches on each tree was followed for the next 18 months. Flush commencement was estimated as the date when shoot elongation was observed for the first time. The flush interval is the number of days between successive commencement dates. Flowering was scored in September 1998 as a scale from 1 (small inflorescence with few flowering branches) to 9 (large inflorescence with many flowering branches). A record was also kept of the proportion of the branches on each tree that flowered. Temperature was logged at the Maroochy weather station, while estimates of daily solar radiation were provided by the Queensland Department of Natural Resources. In this environment, these cultivars flower in October and November, and fruit are harvested in March and April. Trees were grown as commercial crops with respect to watering, fertilizing and pest control (Menzel and McConchie 1998).

Results

Olesen et al. (2000) made a theoretical and practical case for the use of a composite factor (irradiation*temperature) when expressing orchard flushing rates of lychee with respect to the environment. The lead is followed here, as the flushing rates of longan were not greatly dissimilar from those of lychee over a comparable environmental range, although longan appears to have a higher maximum cycling rate than lychee, and is perhaps slower at low irradiation/low temperature conditions. For the longan experiment, mean irradiation during flush development was highly correlated with mean temperature ($r^2 = 0.96; n = 25$ for two cultivars combined).

Essentially linear regressions were fitted to the relationship between flush interval (Figure 1A) and flushing rate (Figure 1B) against irradiation*temperature, as there were no obvious curvilinearities, especially at the tails. This is in contrast to lychee (Olesen et al. 2000) where a sigmoidal curve was fitted for flushing rates, and the upper asymptote provided an acceptable estimate of the maximum rate. The fitted curves for the two cultivars were not significantly different from each other (Tukey-Kramer $P_{0.05}$), either with respect to their slopes or their intercepts.

The axillary buds grew shortly after the longans were pruned. Consequently, staggered pruning resulted in trees with a range of flushing cycles, and those trees with phases which favoured winter flush emergence were expected to flower better than those which did not. To test this, variation in flowering was sinusoidally regressed against pruning date (Figure 2). Neither of the two fitted sinusoids was significant (probability = 11% in both instances), but there was some suggestion of the expected trend, and the estimated periods of the curves (53 days for Kohala and 42 days for...
Chompoo) were close to the flushing intervals expected for late spring through to mid-summer (the clusters at high irradiation*temperature in Figure 1A).

**Discussion**

The results for longan were broadly consistent with those for lychee. Longan may have a shorter minimum cycle of about seven weeks compared with eight to nine weeks for lychee, and perhaps slower growth in cooler areas (Figure 1). There were no significant differences between the two cultivars, consistent with the response across the lychee genepool (Chapters 5 and 6).

There was an indication in Figure 2 that longan shared the tendency of lychee to have a sinusoidal floral response to pruning time. The tendency corresponds with the effect of pruning time on the subsequent phase of the flushing cycle and, consequently, on the likelihood of flush emergence in winter, when weather conditions are most conducive for floral induction.

One important difference between the two crops is that longan is harvested much later than lychee, and is often biennial in southern districts. This is because some trees do not have enough time to complete a vegetative flush between harvest and winter. By understanding the physiology of flush develop, it may be possible to devise a pruning strategy which promotes more regular yields from one year to the next and, at the same time, controls tree size. In more northern regions, at least with respect to the earlier varieties, the approach taken with lychee might effectively be employed: tip-pruning shortly after harvest to allow for one flush of vegetative canopy regeneration before winter, when a second, floral flush is likely to follow. The main limitation, at present, to the determination of appropriate pruning times on the basis of long-term weather records, is an accurate estimate of the maximum flushing rate.

Small pruning experiments were carried out on Kohala longan trees growing near Mareeba on the Atherton Tableland in 1996 and 1997. In late March, ten trees were selected at John Magro’s orchard, five pruned, and five untreated. About 0.5 m was removed from each of the terminal branches. Trees were about ten years old. Average yields at harvest were 83 kg tree⁻¹ for the controls and 40 kg tree⁻¹ for the pruned plots. In March 1996, ten trees were selected, and four branches from each left not pruned (non-cropping branches), four pruned at harvest in mid-March, and four pruned two to three weeks later in April. Selected branches were tagged and flushing and flowering patterns monitored. The non-cropping branches produced a vegetative flush in early April and a floral flush in late June, while those that were pruned at harvest produced a vegetative flush in March and leafy and floral flushes in mid July. The branches that were pruned some two to three weeks after harvest were much later, and produced a leafy flush in April and a mixture of leafy and floral flushes in August. The proportion of branches flowering in the different treatments in October was 76, 38 and 29%, respectively. From these results it seems that pruning of longan in northern Queensland should be carried out as soon as possible after harvest.

Further experiments are required to define the optimum pruning strategies for longan orchards in Australia. These experiments need to be expanded to include the popular Biew Kiew cultivar in northern Queensland. Any models developed would need to be evaluated across the various commercial growing areas. Some of the pruning experiments should include treatments where the trees are pruned at flowering. This might reduce biennial bearing, with the added benefit of larger fruit. There are also no data relating yield and leaf area in longan.

**Reference**


Figure 1. Variation in the interval between successive flushes (A) and its reciprocal, the flushing rate (B), with respect to the mean product of daily irradiation and average daily temperature over the course of flush development (irradiation*temperature). Closed circle and solid lines signify the longan cultivar Kohala, while open circles and broken lines signify Chompoo. For (A), the fitted lines were of the form $1/y = 1/(a*x + b)$, where $a = -0.29$, $b = 212$ and the explained variance was 76% for Kohala; and $a = -0.44$, $b = 302$ and the explained variance was 88% for Chompoo. For (B), the fitted lines were of the form $y^{1.5} = (a*x + b)^{1.5}$, where $a = 0.000059$, $b = -0.012$ and the explained variance was 75% for Kohala; and $a = 0.000059$, $b = -0.015$ and the explained variance was 83% for Chompoo. Data collected at Nambour in southern Queensland.
Figure 2. Extent of flowering in September 1998 as a function of pruning time at Nambour in southern Queensland. Closed circle and solid lines signify the longan cultivar Kohala, while open circles and broken lines signify Chompoo. Fitted lines were of the form $y = a \cos\left(\frac{360(x - b)}{c}\right) + a$, with angles in degrees, x in days, and x = 0 arbitrarily chosen as November 10. For Kohala, $a = 38$, $b = 44$, $c = 53$ and the explained variance was 51%; for Chompoo, $a = 22$, $b = 56$, $c = 42$ and the explained variance was 49%.
Effects of Pruning on Cropping of Rambutan in Northern Australia

Summary

The effects of pruning on the growth and cropping of Jitlee and R167 rambutan were studied in a commercial orchard near Darwin in the Northern Territory (lat. 12°S) over three years. There were three treatments: trees were either not pruned (controls); structurally pruned in February; or structurally pruned in February and then tip-pruned in June. The pruning in February removed dead wood, low-lying limbs, crossing limbs and branches that were close to the net. Up to a metre was removed from the top of the canopy with branches up to 35-40 mm in diameter cut. The pruning in June removed 15-20 cm of new terminal growth when nights were cooler than 20°C. Data was collected on shoot growth, yield, average fruit weight and the duration of harvesting.

The number and length of flushes up to flowering were not affected by pruning or cultivar, and varied only slightly with year. The trees produced three to four vegetative flushes with an average length of about 120 mm. Structural pruning alone or when combined with tipping generally delayed the start of harvesting compared with control trees. In contrast, there were no consistent effects on the length of the harvest season or when harvesting finished. Average yields of the plots pruned in February were 24% lower than the controls, and those of the plots pruned in February and June, 37% lower. These yields were equivalent to 5.6 to 15.8 t ha⁻¹ at a density of 200 trees ha⁻¹. Commercial acceptable yields in this environment are about 12 t ha⁻¹.

The lower yields after pruning were probably related to the reduced leaf area supporting the developing crop, although there was also an affect on flowering. The pruned trees had much smaller canopies than the controls, and would be much easier to harvest, spray and net. These results are consistent with the ideas developed for lychee and longan, with floral initiation occurring when new shoots encounter cooler temperatures. The tipping in June appears to have delayed and reduced the level of flowering in the terminal branches. Regeneration of the canopy after pruning seems less of a problem compared with the responses in lychee and longan. This is because all the rambutan treatments had at least two current year growth flushes supporting the developing crop. The economics of pruning in this species, and the application of these results to other growing areas such as northern Queensland is yet to be determined.

Commercial Implications. Rambutan trees were pruned in the Northern Territory and their performance assessed over three years. Pruning after harvest in February was more reliable than tipping in winter. The commercial benefits of pruning in this and other environments are yet to be determined.

Introduction

Rambutan is a tropical evergreen tree from the Sapindaceae, native to Malaysia and Sumatra in Indonesia, and is closely related to lychee and longan. The tree’s natural distribution is restricted to wet tropical conditions, with growth and production restricted once nights fall below 20°C. The tree grows to 18 to 20 m high and produces flowers and fruit on terminal branches. Inflorescences normally appear during the dry season, but can also be produced at other times in some environments, such as Malaysia. This gives rise to two crops per year, although the main harvest is much heavier.

Two reports indicate that flowering in rambutan in Thailand followed three to four weeks of drought or a slight drop in night temperature (Wanichkul et al. 1990, Manakasem 1995), however, the role of these two factors is not very clear. Glasshouse experiments showed that vegetative growth in
rambutan was very sensitive to night temperature (Diczbalis and Menzel 1998). Despite these reports, the exact relationship between flowering and vegetative growth is not known. This information is required before effective pruning strategies can be developed. In other tropical tree crops such as lychee and mango, temperature is the main factor controlling flower initiation (Chaikiattiyos et al. 1994; Batten and McConchie 1995; Menzel and Simpson 1995). Drought is less important.

Little detailed research has been carried out on the effects of pruning on tree size and flowering in rambutan. Ghani and Selleh (1994) showed that removing old panicles following harvest reduced biennial bearing in Malaysia. They concluded that old panicles left on the tree led to asynchronous vegetative growth, which resulted in biennial bearing. Whether some of the branches failed to flower is unknown. We report on the effects of pruning on the growth and cropping of rambutan in a commercial orchard near Darwin in the Northern Territory (12°S) over three years. Pruning was carried out in February (structural) or in June (tipping). The two main commercial varieties, R167 and Jitlee, were used in the experiments.

Materials and Methods

Experiments were conducted on grafted eight-year-old R167 and Jitlee rambutan trees in a commercial orchard south of Darwin with a deep red sandy loam. The trees had been heavily pruned two years earlier, prior to permanent netting of the orchard for bird and bat control.

Trees were structurally pruned in February after harvest or structurally pruned in February and tip-pruned in June. There was also a set of control trees where branches were lightly pruned during harvesting (Lim and Diczbalis 1998). The pruning in February removed dead wood, low-lying limbs, crossing limbs and branches that were close to the net. Up to a metre was removed from the top of the canopy with branches up to 35-40 mm in diameter cut. The pruning in June removed 15-20 cm of new terminal growth when nights were cooler than 20°C.

The length of flushes was measured weekly from eight terminals per tree, and the number of flushes up to flowering, yield per tree, harvest period and average fruit weight recorded. There were three blocks of six trees, with three trees of each cultivar. Data are presented as treatment means with standard errors.

Results

Flushing

The number and length of flushes up to flowering were not affected by pruning or cultivar, and varied only slightly with year (data not presented). The trees produced three to four vegetative flushes with an average length of about 120 mm.

Harvesting

Structural pruning alone, or when combined with tipping, generally delayed harvest compared with the control trees (Table 1). Both cultivars showed this response (except for Jitlee pruned in February in 1996 and R167 pruned in February 1998). The greatest effect occurred in 1997 when the pruned trees were 4 to 6 weeks later.

Table 1. Effects of pruning and cultivar on the commencement of harvesting in rambutan in the Northern Territory over three years. Data are means of three trees per treatment.
Control 26 Oct 15 Oct 6 Nov 22 Nov 3 Dec 9 Dec  
Pruned in February 19 Oct 29 Oct 25 Dec 30 Dec 7 Dec 28 Nov  
Pruned in February/June 23 Nov 26 Nov 16 Dec 23 Dec 30 Dec 7 Dec

Table 2. Effects of pruning and cultivar on synchrony of harvest (weeks to 2/3 harvest) of rambutan in the Northern Territory over three years. Data are means of three trees per treatment. Maximum standard error of means also shown.

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Yield and average fruit weight

There were no consistent effects of the February pruning on yield across year and cultivar (Table 3). However, on average, the yields of these plots pruned were 24% lower than the controls. The yields of the plots pruned in February and June were significantly lower than the controls most years (average 37% lower). These yields are equivalent to 5.6 to 15.8 t ha\(^{-1}\) at a density of 200 trees ha\(^{-1}\), with the higher values close to the maximum yields for rambutan in northern Australia. Average fruit weight was 32 g for Jitlee and 34 g for R167. There was an effect on pruning on average fruit weight in some years, however across the three years, the treatments had similar fruit weights (Table 4).

Table 3. Effects of pruning and cultivar on yield of rambutan (kg per tree) in the Northern Territory over three years. Data are the mean of three trees per treatment. Maximum standard error of means also shown.

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Yield and average fruit weight

Table 4. Effects of pruning and cultivar on average fruit weight of rambutan (g) in the Northern Territory over three years. Data are the means of three trees per treatment. Maximum standard error of treatment means also shown.

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Discussion

In Malaysia and Thailand, rambutan trees are pruned to maintain productivity and synchronise the harvest. In general, there are two types of pruning, with training for tree shape every few years and annual pruning of terminals to control tree size (Tindall 1994).

In South-East Asia, the shape of rambutans in the early years is considered to have a strong effect on subsequent production, with the young budded tree pruned to a central leader about 1.0 m high. The apical shoot is then pruned to encourage the development of three to five well-spaced lateral branches. In the first one to two years of growth, pruning of lateral branches continues until a suitable shape is obtained. The idea is to develop an open centred tree with good ventilation. Annual pruning is relatively light and confined to the removal of water shoots, dead or dying branches, and branches low to the ground (Tindall 1994). This is also practiced in Australia, without any specific guidelines, and an unknown impact on cropping.

The responses to pruning in the present experiment were quite variable (Table 3). Trees pruned in February had on average 24% lower yields than non-pruned trees, while those pruned in June as well, were about 37% lower. The lower yields were probably related to the reduced leaf area supporting the developing crop, although there was also an affect on flowering. Pruned trees were much smaller, and would be easier to pick, spray and net, and could be planted at close spacings.

Olesen et al. (2000) carried out a series of pruning experiments on lychee and developed a model to predict the optimum time of pruning in eastern Australia. The objective was to prune the trees so that they produced a new flush in winter when conditions were ideal for flower initiation. In northern areas, there was the opportunity to prune for two flushes after harvest, while in southern areas, the best yields were recorded when trees were pruned to produce a single flush after harvest. This technology is based on lychee trees flushing in a predictable way with weather (temperature and solar radiation), and flower initiation occurring when early flush development coincides with days below 20°C. Whether this approach has application in rambutan is not known.

All the treatments in Darwin produced three to four flushes before the rambutans flowered. The physiology of flowering in rambutan requires further research. There was some indication that rambutans might follow the model developed for lychee and longan, with flower initiation occurring when new shoots encounter lower temperatures in winter. This is supported by the data collected for the trees which were tipped in June. These plots cropped later and had lower yields than the controls, suggesting that flowering was much later, and that many of the terminal shoots missed the period of cool inductive weather. Presumably, the critical temperature required for flowering in rambutan is much higher than that for lychee or longan, because nights seldom fall below 20°C in this environment. It is also possible that the period of induction is also much shorter. Dry weather at this time might assist flowering.

Pruning delayed flowering and the time of harvesting by up to 6 weeks compared with the non-pruned trees. Pruning undoubtedly can alter the production season of rambutan in the Northern Territory, however, the economic impacts of these changes are unknown.

Conclusions

Pruning delayed the harvest of rambutans growing in a commercial orchard in the Northern Territory. Yields were also 20 to 40% lower compared with non-pruned trees, but on much smaller canopies.
The reduction in cropping was greatest when structural pruning in February was followed by tipping in June. The economics of pruning in this species, and the application of these results to other growing areas is yet to be determined. Possible future areas of research include developing models of flush development and flowering (Olesen et al. 2000), and defining the optimum leaf area for fruit production (see Chapter 7).

References


General Discussion, Conclusions and Recommendations

Lychee, longan and rambutan are related members from the family Sapindaceae which produce fruit containing an edible aril. Lychee and longan are subtropical, but their distribution also extends into the tropics at elevation. About 90% of lychee production in Australia comes from northern, central and southern Queensland, and the balance from northern New South Wales. Most of the longan orchards are in northern Queensland, with much of the recent expansion on the Atherton Tableland. In contrast, rambutan is strictly tropical, with the bulk of trees in northern Queensland (Lim and Diczbalis 1998; Menzel and McConchie 1998).

These crops all eventually grow into large trees that are difficult to spray, harvest and net. More than half of the lychee crop can be lost each year to birds, bats and fruit-piercing moths. Exclusion netting is an effective way to control these pests, but is most practical with small trees. Small trees can also be closely planted and provide greater returns in the early life of an orchard. The other issue affecting the lychee and longan industries is irregular flowering and poor fruit retention. This is generally related to the pattern of shoot growth during the period after harvest and up to the time of flower initiation.

The objective of the project was to develop pruning strategies to stabilize production and reduce tree size. Most of the research was on lychee, with fewer experiments on longan and rambutan.

Lychee trees were pruned in southern districts and the interval between shoot flushes correlated with temperature and solar radiation. These correlations were used to develop a model to predict the best time to prune trees in summer or autumn for maximum cropping, which was then tested in a series of pruning experiments along the eastern seaboard of Australia. Finally, sets of trees with young red flushes going into winter were pruned or sprayed with ethephon to test whether these treatments might be effective alternatives or adjuncts to pruning earlier in the year. In longan, trees in northern Queensland were pruned to determine whether similar responses to those for lychees could be elicited. A model was also developed relating shoot growth to weather. In rambutan, the effects of pruning on tree performance were investigated near Darwin in the Northern Territory.

Lychee

**Modeling growth**

Provided lychee trees are well managed, the time between successive flushes depends on the amount of sun and prevailing temperatures (Figure 1). Trees must also be routinely sprayed for pests that might damage the young leaves. Generally, the flushes mature more quickly in full sun and at higher temperatures, since the leaves produce more sugars, which provide the energy and carbon skeletons for growth and development. However, there is an upper limit, and lychee trees do not seem to be able to cycle much faster than about one flush every 60 days even in the warmest, brightest environment.

Under-fertilizing slows down flushing by scaling the rate of development in line with the availability of essential minerals. Drought also reduces the growth of new leaves and shoots. By contrast, substantial damage to new leaves by caterpillars can cause new flushes to emerge prematurely. This is possibly because the immature leaves of flush produce a signal which suppresses further bud development. Damage to the leaves weakens the signal so that new buds can develop.
Predicting the optimum time of pruning

The results from Figure 1 were applied to long-term weather records to characterize flush development at 16 locations along the eastern coastline where lychee is grown commercially (Grafton to Mossman) for each recorded year. Of particular interest, was the expected date in autumn that would provide for growth of a second flush around the time of the winter solstice. That is, the timing of an autumn flush favourable to a subsequent winter flush.

From this starting point, we calculated the approximate autumn flush emergence dates representing, historically, the completion of at least one vegetative flush by winter. We then translated the emergence dates into corresponding pruning dates by assuming buds emerge one week after pruning (Figure 2). In this way, we have calculated pruning times which allow for rejuvenation of the canopy before flowering. Without such rejuvenation, yields will be dramatically reduced (Chapter 6). The effect of structural pruning on lychee production requires further investigation.

To use Figure 2, the latitude of the farm is found along the horizontal axis and the estimated pruning date is read off the vertical axis, as illustrated for some of the major centres. As expected, the estimated pruning date is later in the year the further north one travels, owing to the increasingly warmer and brighter weather conditions. The quicker growth in northern coastal areas, however, may not necessarily contribute to heavy yields.
Figure 2. Latitudinal variation in the estimated optimum date of pruning for lychee in eastern Australia.

Evaluating the predictive model

The estimated pruning date is only a first approximation, and needs to be refined by trial and error on each farm, and by consultation with other growers and service providers. It is only a first approximation for well-cared for trees.

We have made several attempts at refining pruning times in commercial orchards. Two examples are presented here. As predicted from the model, trees pruned in late February in Bundaberg completed their first vegetative flush by winter, and had a second flush during cool weather in winter. This group of trees flowered and cropped heavily. Trees pruned in early February, hardened-off a flush by late autumn, and produced a second flush before winter, that was mostly vegetative. Trees pruned in late March did not harden-off the first flush until early spring. They also did not flower and crop.

We conducted a more elaborate trial near Mareeba, and pruned trees at ten-day intervals from late January through to late March. To achieve two vegetative flushes by winter and good flowering, trees would need to have been pruned in early to mid-January in this environment that year. Similarly, to achieve one vegetative flush by winter and good flowering, trees would have needed to have been pruned in early to mid-March. By contrast, trees pruned in mid-February tended to produce a second vegetative flush in late autumn. They generally produced a third vegetative flush in spring.

These examples are results for single years. Such observations over a number of years are required to truly understand the behaviour of the trees in a given orchard. However, a number of generalizations can be made. The time between successive flushes during autumn leading into winter for healthy trees is unlikely to vary dramatically between cultivars. The time between harvest and winter in north Queensland is sufficiently long for growers to have the option of rejuvenating the canopy by either one or two vegetative flushes, while in southern Queensland there is seldom time to complete more than one flush by winter.

Remedial measures
The recommendations for pruning after harvest in the different districts are based on long-term weather data, and a model of flush development. They represent an historical guarantee of at least one vegetative flush by winter (Figure 2). However, in some years, the weather will be considerably warmer and brighter than the coldest, dullest year, and trees will produce a second flush in late autumn that will not flower.

At the moment, there are broadly two ways to deal with this possibility. Firstly, following the lead of Israeli and some South African growers, trees might be droughted once the post-pruning autumn flush has fully elongated, preventing further flush emergence until the trees are re-irrigated in winter. Such a strategy is clearly only possible in areas with distinct dry periods in winter, and thus is probably only applicable in Mareeba or possibly Bundaberg. There is also a problem in that the degree and timing of the drought have not been defined.

Secondly, the late-autumn flush might be delicately pruned-off, or selectively defoliated chemically, just prior to winter. Both courses of action promote a winter flush soon afterwards. The chemical option is more convenient than the pruning one, but the testing of defoliants is still only at the experimental stage, and the main defoliant that we are dealing with, ethephon, is not yet registered for lychee. With the pruning option, care must be taken not to remove the leaves of the mature flush behind the late autumn flush, as this will tend to reduce yields.

Either the pruning, or the defoliation of late autumn flushes with ethephon (as 1 to 3 litre of ethrel and 5 kg of urea per 1000 litre of water), increased flowering with respect to the non-treated control trees in experiments at Bundaberg. These remedial measures can also be used to correct the flushing patterns of trees that have not been pruned in the current season. However, a winter flush in northern Queensland is no guarantee of flowering, because of the short period of cool weather in some years. Furthermore, flowering is no guarantee of fruit set or a good crop. The effects of girdling on flowering in north Queensland is worth examining.

**Longan**

Longan is a popular fruit in South-East Asia, with substantial production in China, Vietnam and Thailand. In Australia, it is generally grown in the same areas as lychee, although most of the orchards are in northern Queensland, particularly on the Atherton Tableland. It is less common in southern districts (Menzel and McConchie 1998). Longan trees can grow into large specimens which are difficult to spray, pick and net. There are also problems with irregular flowering related to the pattern of shoot flushing after harvest. However, unlike lychee, fruit set and retention can be very heavy.

Longan is similar to lychee in that it grows by repeated flushes (Olesen *et al.* 1996) and requires cool weather during early flush development for floral induction to occur (Nopodol Jarassamrit, unpublished data). Consequently, it is open to similar canopy management practices. Results collected from staggered pruning experiments at Nambour in southern Queensland, showed that the interval between successive flushes was strongly related to the product of irradiation and temperature in cultivars Kohala and Chompoo. There was also a trend with flowering against pruning date which followed a sinusoidal pattern, with the estimated periods of the curves (53 days for Kohala and 42 days for Chompoo) close to the flushing intervals expected for late spring through to mid-summer.

The results for longan were broadly consistent with those for lychee. Longan may have a shorter minimum cycle of about seven weeks compared with eight to nine weeks for lychee, and perhaps a less temperate/more subtropical range. With further data collection, a model could be developed and applied to long-term weather records from across the geographic range over which longan is grown, to illustrate the latitudinal variation in flush development, as shown for lychee. This could be then used to estimate the optimum time of pruning in different locations. Results from preliminary experiments with mature trees near Mareeba on the Atherton Tableland suggest that pruning of longan in northern
Queensland should be carried out as soon as possible after harvest. In southern districts, there are problems with completing a vegetative flush before winter, especially in late maturing cultivars.

**Rambutan**

Rambutan is strictly tropical, whereas lychee and longan are subtropical. The natural distribution of rambutan is restricted to wet tropical conditions, with growth and production poor once nights fall below 20°C. Rambutan is popular within Malaysia, Indonesia, Thailand and the Philippines, but in Australia is mainly confined to the area around Cairns and Tully in northern Queensland and just south of Darwin in the Northern Territory. There are reports from Thailand that flowering is related to a few weeks of drought or cooler weather (Wanichkul *et al.* 1990, Manakasem 1995), while glasshouse experiments in Australia showed that vegetative growth is very sensitive to night temperature (Diczbalis and Menzel 1998). However, the exact relationship between flowering, vegetative growth and weather is not known. This information is required before effective pruning strategies can be developed.

The responses of rambutan to pruning in the Northern Territory were quite variable. Jitlee and R167 trees pruned in February had on average 24% lower yields than non-pruned trees, while those pruned in June as well, were about 37% lower. The lower yields were probably related to the reduced leaf area supporting the developing crop, although there was also an effect on flowering. Pruned trees were much smaller, and would be easier to pick, spray and net, and could be planted at close spacings.

All the treatments in Darwin produced three to four flushes before the trees flowered. There was some indication that rambutans might follow the model developed for lychee and longan, with flower initiation occurring when new shoots encounter lower temperatures in winter. Presumably, the critical temperature required for flowering is much higher than that for the other two species, because nights seldom fall below 20°C in Darwin. It is also possible that the period of induction is also much shorter. Dry weather in winter might assist induction.

The economics of pruning rambutan, and the application of these results to other growing areas such as Cairns and Innisfail, with a less distinct dry season is yet to be determined. Possible future areas of research include developing models of flush development and flowering (Olesen *et al.* 2000), and defining the optimum leaf area for fruit production.

**References**


Implications

Profitability in lychee

Thew (1986) examined the profitability of orchards in southern Queensland, with average yields of 4.6 tonne per ha and a price of $3 per kg. These yields and returns are probably on the low side for orchards in southern districts. Nevertheless, his analysis is useful for examining the effect of picking rate, price, and variable costs. He found that a 10% increase in price improves profitability more than a 50% reduction in growing costs. Given this, and given the often high rate of fruit deterioration from farm-gate to market, it may be that there are more gains to be had in improving the handling of fruit than in reducing inputs. Thew also examined the effect of close plantings, and concluded that they had no economic advantage compared with traditional plantings, however his analysis was based on similar yields (4.6 vs. 4.7 tonnes per ha, respectively) in the two systems.

![Figure 1. Costs associated with producing an 11 tonne lychee crop in southern Queensland over 20 years. Data from Hassalls and Associates (Hyde 1999).](image)

Hassalls and Associates (Hyde 1999) studied the profitability of an 11 ha Kwai May Pink orchard in southern Queensland over 20 years, assuming yields of 11 tonne per ha (275 trees per ha), a price of $5 per kg and netting costs of $16500 per ha. The various costs associated with producing the crop are shown in Figure 1. Picking, packing and marketing were the most expensive part of the operation, and accounted for about 65% of total costs. These data further illustrate that there is little benefit in trying to reduce the costs of watering, fertilizing and spraying, while there are potential benefits to be gained by improving the efficiency of harvesting etc. Gross margin was $33,897 per ha after subtracting recurring costs of $21103 per ha from revenue of $55,000 per ha. Net margin after investment costs of $4806 per ha was $29,091 per ha. The gross margin was zero when revenue was reduced by 62% or recurring costs were increased by 161%. The net margin was zero when revenue was reduced by 53%, recurring costs were increased by 138% or investment costs were increased by 605%.
Table 1. Effect of netting, pruning and plant spacing on yields and returns in lychee. The analysis assumes 30% loss of fruit to birds and bats and a 10% extra loss to insect pests in the traditional orchard. Yields of pruned trees are 30% lower than the yields of non-pruned trees (similar yields on a canopy area basis). There are 150 trees per ha in a traditional planting and 300 trees in a high density planting. The price for fruit is $5 per kg.

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Hinton (1999) examined costs and returns for a 13 ha Fay Zee Siu orchard on the Atherton Tableland, assuming yields of 3.7 tonne per ha (154 trees per ha) sold at $8 per kg. Nets were hung over the trees at a cost of $6,160 per ha. The gross margin was $18,760 per ha after subtracting recurring costs of $10,840 from the gross revenue of $29,600 per ha. Harvesting and marketing accounted for 87% of variable costs. The two most critical factors affecting profitability were yield and price. At yields of 12, 24 and 36 kg per tree, farms were profitable at prices above $10.20, $6.00 and $4.60 per kg, respectively. Capital outlays were not included in the analysis, but were approximately $1,200 per ha for each year of the 30 year project. Land was only $3,000 per ha, about a third of the cost in southern Queensland.

The impact of pruning, netting and plant spacing on returns in lychee

Table 1 shows the relative returns for three different orchards: a traditional non-netted orchard with 150 trees per ha and trees not pruned; a netted and pruned orchard with 150 trees per ha; and a netted and pruned orchard with 300 trees per ha. The analysis assumes 30% loss of fruit to birds and bats and a 10% extra loss to insect pests in the traditional orchard. Yield of pruned trees are 30% lower than the yields of non-pruned trees. However, yields are similar when expressed on a canopy surface area basis (Chapter 7). The price for fruit is $5 per kg.

The data in Table 1 show that returns are greater after pruning and netting, especially when trees are planted at close spacings. Some existing orchards are suffering losses of up to 60% due to birds and bats, so the net impact of pruning/netting would be substantially greater. There are of course additional costs associated with this system, including $1,650 per ha for extra plants, $1,875 for extra irrigation and $16,500 for nets. Not taken into account in this analysis is the savings associated with harvesting smaller trees. Thew (1986) indicated that relative gross margin improved by more than four-fold when the picking/packing rate increased from 50 to 150 kg per man day. His analysis
assumed a yield of 4.6 t per ha and a price of $3 per kg. Further analyses are required to determine the economic benefits to lychee growers, and the potential implications for longan and rambutan growers.

References


Industry Extension

Lychee and longan

Activities in 1995 and 1996

Trevor Olesen and Chris Menzel held a farm walk at the longan trial site near Mareeba (John Magro’s farm) on June 15, 1995. It was attended by about ten longan growers from the Atherton Tableland. Trevor and Chris gave the background to the project and discussed some of the pruning treatments which had been applied. Trevor Olesen, Cameron McConchie and Chris Menzel also held a field day after the lychee harvest in north Queensland (March 15, 1996) at Barry Hartley’s lychee farm at Mareeba to discuss the results from the first year of the pruning experiments in north Queensland, south Queensland, New South Wales and the Northern Territory. The field day was attended by about 30 lychee growers, consultants and extension staff.

Trevor Olesen, Cameron McConchie, Chris Menzel and Neil Greer attended a meeting of South Queensland Lychee Growers at Nambour on September 29, 1995 The main focus of the meeting was to discuss the results of the lychee postharvest and marketing project, however, Trevor gave the background to the canopy project and discussed briefly some of the main results. A field day was also held at the lychee trial site near Bundaberg (Derek Foley) on October 11, 1995. It was attended by about 60 growers who came from as far as Rockhampton and northern New South Wales.

The major extension activity during 1996 was the Fourth National Lychee Seminar held at Rockhampton from September 26-28. The seminar was very well organized by the local committee from the Australian Lychee Growers’ Association (ALGA) and the Queensland Department of Primary Industries (QDPI) and attracted over 150 lychee and longan growers. The seminar consisted of two days of formal presentations, followed by a field day to two commercial fruit enterprises on the Saturday. Both these farms were netted indicating the interest in controlling tree size in lychee and longan. During the seminar, Trevor Olesen gave a talk highlighting the results of the first year of the pruning experiments in eastern Australia.

Activities in 1997

Northern New South Wales. A major extension activity in 1997 was the Canopy Management Field Day at Byron Bay in northern New South Wales on January 23, just before the harvest of the Kwai May Pink crop. The seminar was organized by the Queensland Department of Primary Industries (QDPI), CSIRO Division of Horticulture and the New South Wales Department of Agriculture (NSW Ag), and attracted growers from NSW and southern Queensland, including representatives of the Australian Lychee Growers’ Association (ALGA).

During the field day, Trevor Olesen gave a talk highlighting the results of the pruning experiments at Byron Bay Lychee Farm which showed that pruning could be used to alter flushing and flowering patterns. Cameron McConchie demonstrated the commercial potential of cuttings for lychee plantings. This is based on a system of semi-hardwood cuttings rooted in a mist chamber under glass. Queensland. There were Canopy Management Field Days at Bundaberg in southern Queensland on November 6 and at Mareeba in northern Queensland on November 14. About 100 lychee growers attended the field days organized by Chris Menzel, Cameron McConchie and Trevor Olesen. Team members summarized the results of the pruning experiments in the various lychee and longan growing areas, and gave an update on the use of cuttings for propagation. They also discussed the objectives of the new project over the next 18 months.

The canopy project was also discussed at two meetings in north Queensland (Cairns) on September 26 and in southern Queensland (Nambour) on October 22 with representatives of the Australian Lychee Growers’ Association (ALGA) and the Queensland Fruit and Vegetable Growers (QFVG). Cameron McConchie,
Trevor Olesen and Christopher Menzel gave slide presentations on the results of the pruning trials in the different growing areas.

Activities in 1998

The main extension activities during this period were the demonstration blocks in commercial orchards in northern Queensland, central Queensland, southern Queensland and northern New South Wales. There were also field days held in Mareeba on September 11, Bundaberg on September 24 and Nambour on October 29. These field days attracted about 120 lychee growers (see publications).

Activities in 1999

The canopy management team attended the Fifth National Lychee Conference at Twin Waters on the Sunshine Coast in September 1999 and presented three papers on flushing cycles and flowering in lychee, factors affecting profitability in the lychee industry, and future directions for the lychee industry (see publications). They also had a poster presentation on canopy management in lychee, and released a brochure highlighting the main results of the project (see publications). The Conference and associated field day were attended by about 160 growers.

To summarize, there have been about ten field days, and at least five formal presentations at industry conferences and workshops. There have also been over twenty publication produced during the project (see publications). The recommendations from the canopy management project will be incorporated into the forthcoming Queensland Department of Primary Industries Lychee Information Kit to be released early next year.

Rambutan

Reports on the rambutan pruning trials south of Darwin were given to industry at the Northern Territory Horticulture Association/Northern Territory Department of Primary Industry Exotic Fruit Workshops in May, 1996-99 by Yan Diczbalis and Chris Wicks. There were also informal farm visits to the trial site during this period. Yan Diczbalis gave a report on pruning strategies for northern Queensland growers at a Far North Queensland Rambutan Marketing Group Field Day in August, 1999.
Overview

This project has shown that lychee trees can be pruned and have similar yields to non-pruned trees when production is expressed on a canopy surface area basis. The pruned trees are of course, smaller, and are easier to harvest, spray and net, and can be planted at close spacings for higher returns. The optimum time of pruning varies in a systematic way along the eastern coastline, in response to increasing radiation and temperatures in tropical areas compared with subtropical localities. Suggested times of pruning for different locations are as follows: Cairns, March 7; Mackay, February 27; Rockhampton, February 22; Bundaberg, February 20; Nambour, February 16; and Murwillumbah, February 13. The suggestion is to remove 30 to 50 cm from each terminal right around the tree. This can be done with small hedge trimmers or large pruning saws with contractors, depending on the size of the trees and size of the orchard. At this stage, there is no information to suggest that cultivars need to be pruned at different times in any one location. Trees should be well-watered and fertilized for consistent cropping. Attention should also be paid to leaf-eating caterpillars and beetles which can disrupt the desired flushing patterns induced by pruning.

If out-of-season young leaf flushes develop in winter, the trees will generally not flower. These can be lightly pruned off mechanically. If more than a few centimetres are removed at this stage, the crop will be very light, since the developing fruit are dependent on these leaves for their growth. Experiments have shown that ethephon sprays are very effective for selectively removing these young winter flushes and promoting flowering, but this treatment has not been registered.

Structural pruning can be carried out at the time of hedging, or preferably after panicle emergence. Pruning helps to keep the trees small, and improves light distribution to the lower parts of the canopy. At this stage, it is recommended that no more than 20% of the internal branches be removed. The idea is to remove the branches which do not support sunlit leaves and fruit. The optimum leaf area required for fruit production requires further research.

Longan appears to be similar to lychee with regard to flushing patterns and flowering. Limited information suggests that pruning in northern Queensland should be carried as soon as possible after harvest. No recommendation can be given for other districts. In rambutan, pruning after harvest reduced average yields by about 25%, although the trees were smaller. No optimum times of pruning have been established for this crop.
Publications


Olesen, T., Menzel, C. M., Batten, D. J., McConchie, C. A. and Jones, P. N. (2000). Effects of pruning on the flushing cycles and flowering of lychee. *Australian Journal of Botany*
