New tree training systems for custard apple

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QLD Department of Primary Industries & Fisheries

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FINAL REPORT FOR HAL PROJECT CU04004 (Completion date October 2007)

NEW TREE TRAINING SYSTEMS FOR CUSTARD APPLE

Roger Broadley et al.

HORTICULTURE AUSTRALIA LIMITED

This project was funded by the Australian Government through Horticulture Australia Limited (HAL), and the Australian Custard Apple Growers Association (ACAGA).

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This is an integrated research, development and extension project where the following team members all contributed significantly to successful project outcomes.

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Trevor Olesen	NSW Department of Primary Industries
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Bob Nissen	Senior Principal Experimentalist, QDPI and F

This is the final report for RD and E work conducted for the Australian custard apple industry from 2004-2007.

Date of report: October 2007

MEDIA SUMMARY

A combination of new varieties and training systems is set to revolutionize the Australian custard apple industry. A new variety, KJ Pinks, sets 50% of its flowers compared with older varieties which set less than 3%. In this study we showed that this new variety is very suitable for higher density training systems such as the Maroochy V trellis and hedgerow systems.

The Maroochy V trellis is planted at 800 trees per hectare compared with about 300 trees with the standard open vase system. Consequently early yields on this system are higher than for vase-trained trees. On a commercial farm, four-year-old trees on Maroochy V trellis produced six trays per tree, or about 5 000 trays per hectare, and at full maturity, we predict that this system will produce in excess of 6 500 trays per hectare. Regional trials to compare the different training system have now been set up from north Queensland to northern NSW.

We have also investigated the use of mechanical pruning to reduce tree size and labour costs associated with pruning, thinning and harvesting. Early findings appear promising showing that mechanical pruning during dormancy and mid-late summer is feasible and that tree height can be maintained at less than 3m. Additionally, preliminary studies have also shown that growth retardant may reduce shoot extension growth and increase yields by 20%.

Further longer-term studies are planned.

TECHNICAL SUMMARY

- A series of observation trials were established at Maroochy Research Station and at three custard apple orchards in eastern Australia (Yeppoon, Alstonville and Atherton) to investigate new training systems for custard apple. Two new training systems, hedgerow and Maroochy V-trellis, were compared with standard vase trained trees. Managing foliar light interception is one of the key factors in creating the most productive fruit orchards. Most studies with temperate fruits have shown about 60% of total light at mid-season needs to be intercepted by the leaf canopy and of this light a minimum of 20% of full sunlight needs to be transmitted to actual fruiting sites within the tree canopy to maximize fruitfulness.
- The objective of the studies was to improve light interception, reduce tree size, increase productivity and fruit quality and reduce costs associated with harvesting and orchard management.
- We developed new protocols for training the Maroochy V trellis systems to enhance precocity of bearing. We also evaluated new pruning and growth management systems for the hedgerow system. We found that excessive tree vigour was found to be a major problem with older tree training systems. New methods of controlling tree vigour, including use of growth retardants and dwarfing rootstocks, were and are continuing to be investigated.
- New pruning methods are being developed to enhance performance of the new training systems. Leaf stripping was an effective technique to increase and spread flowering. A new variation of this technique has been developed which helps to reduce shoot extension growth. Summer pruning in January was successful to preventing further extension growth. This operation could be done mechanically on hedgerow trees. The growth retardant Sunny was effective in increasing yield of hedgerow system at Glasshouse Mountains. In several studies it appears to have a mild to moderate growth retarding effect. There was an economic benefit of about $28 000 per hectare for a cost of about $6200 per hectare for the Sunny.
- We found that hedgerow systems could be successfully mechanically pruned when dormant and again mid-summer to reduce tree height to less than three metres, thus greatly reducing labour cost associated with thinning, pruning and harvesting. However, we found that mechanical pruning did not totally eliminate the need for hand-pruning which is still necessary to remove limbs which crowd the centres of trees.
- Higher yields were achieved with trees grown on the Maroochy V trellis and under exclusion netting. We predict that this system at full maturity will produce 5 000–6 000 trays per hectare with a gross economic return of about $150 000. Exclusion netting appears to create a favourable environment for fruit set and greatly improves fruit quality by increasing fruit size and reducing blemishing and fruit cracking.
- To date we have found only one cultivar, KJ Pinks, which is suitable for the Maroochy V trellis because of its high fruit setting ability and because it can set fruit on vigorous shoots. However, other high fruit-setting varieties are being bred at the Maroochy Research Station.

REVIEW OF LITERATURE

Light

Orchard light interception and distribution are the keys to high yields and fruit quality (Lakso, 1994; Robinson, 1997). Sunlight intercepted by leaves provides the energy to drive the process of photosynthesis, which is fundamental to the growth and fruiting of all plants. Without the capture of sunlight, trees cannot manufacture the carbohydrates and food required to produce high yields of good size, well-coloured, high quality fruit.

Although light intensities in Australia are high relative to other countries, many commercial orchards do not attain their full yield and fruit quality potential. Middleton et al. (2007) suggest that low productivity can broadly be attributed to either

(a) insufficient tree size and canopy volume,
(b) excessive tree vigour and internal shading.

Varying light interception also affects leaf morphology (Marini and Corelli-Grappadelli, 2006). When light levels are too low, leaves tend to be thicker and heavier in an attempt to intercept more light for photosynthesis. This can be observed by comparing specific leaf weights (leaf weight/leaf surface area).

Light interception can be measured by comparing light levels at the top of the tree and the base of the tree. An effective large scale measure of potential light interception is the dimensionless Leaf Area Index (LAI), which gives a guide as to how much a tree fills its allotted volume. It is calculated as a ratio of leaf area (m^2)/orchard floor area (m^2) (Middleton et al., 2007).

Light management

Maintaining a narrow canopy depth in all directions from which sunlight reaches the tree, including reflection from the ground or mulch, creates an ideal microclimate for fruit growth. The more leaves there are at a certain point in the canopy, the less likely it is for light to penetrate the canopy. Hence, in productive orchards, all fruit-bearing regions are never far from an outside surface of the tree.

Ideal light interception for apple orchards is about 60% of available light (Middleton et al. 2007) and can be achieved with an LAI between 2 and 3. Too much interception (>70%, LAI >3) can lead to internal shading, resulting in unequal quality and smaller fruit. Lower light interception equals higher light transmission, resulting in sunburnt fruit.

Where trees are over-vigorous with light interception >60% and LAI approaching 3.0 or above, marketable yields will improve with control of tree vigour and attention paid to individual tree architecture, pruning, leaf distribution and branch orientation.

Vigour control techniques such as summer pruning, trunk girdling, root pruning and regulated deficit irrigation (RDI) may be appropriate in these situations (Marini and Grappadelli, 2006; George et al, 2006).

Heavy pruning and/or the application of additional water and fertiliser are undesirable tree management options. In most cases these strategies will have little beneficial effect on the vigour and productivity of mature trees, and will more likely reduce yield and fruit quality through excessive vegetative growth and the resultant shading.

Even in well-illuminated trees, where considerable light penetrates the canopy and reaches the orchard floor, some parts of the tree may still receive less than 10% of incident sunlight levels throughout the day. At such low light intensities, fruit set and quality in these regions is poor, and trees require restructuring to open up the canopy (Marini et al., 1990, 1991).

Other variables like rootstock dwarfing ability can play a part in orchard management options which affect the levels of light interception (Marini and Grappadelli, 2006).

The two aims in the design, planting and management of orchard systems are to:

- Create and maintain a desirable tree form (height, shape, spread, Tree Row Volume) that intercepts approximately 60% of daily sunlight in midseason.
- Ensure sufficient light can reach all parts of the canopy to maximise yield and fruit quality throughout the tree (tree architecture, leaf area).

Productivity

Current yields of existing custard apple (*Annona* spp. hybrids) varieties grown in traditional open vase systems are low and variable. Yields of 10-12 tonnes per hectare are being achieved, but this productivity is low compared with innovative tree management systems used commercially for apples and stonefruit. In these latter crops, high yields of fruit vary from 40-70 tonnes per hectare. Light interception and transmission in custard apple canopies is poor due to excessively dense foliage and tree vigour. This adversely affects fruit size and quality. Consequently, methods of controlling tree vigour through tree training and pruning systems are urgently required.

Training systems for fruit crops

Many different training systems have been developed for fruit crops. The most advanced systems have been developed for temperate fruit such as apple and stonefruit. Fewer studies have been conducted on new training systems for subtropical and tropical fruit species. However, in recent years hedgerow systems have been developed for lychee, avocado and mangoes with trees being mechanically pruned annually.

Besides improving light interception, more advanced tree training systems can also increase profitability through improving labour use efficiency by allowing easier access for fruit picking and tree maintenance. Tree planting density can also be increased with certain training systems. Training methods are proven effective by their end results - fruit yield, size and quality, along with consistency in results, and profitability.

Common tree form and crop training systems include:

- vase shape
- central leader (vertical axis, slender spindle etc)
- palmette
- Closed and open V-trellis (Tatura trellis)
- Y and V

Variations of the Y and V trellis systems have developed from the Tatura trellis developed for mechanical harvesting of cling peach in Australia (Chalmers et al., 1978). With some training systems such as the Tatura, the tree structure and fruit is supported by wires on specially constructed trellises.

Mechanical pruning

Increasingly temperate fruit orchards are moving towards mechanisation to reduce labour costs (Marini and Corelli-Grappadelli, 2006). Mechanically pruning is currently used extensively in the mango and avocado orchards throughout Queensland to control tree size. This system has been trialled on several custard apple orchards in the Bundaberg and Yeppoon regions. Mechanical pruning may be best suited to the very high yielding varieties of custard apple such as African pride and KJ Pinks.

New Varieties

A new custard apple variety called KJ Pinks has recently been released to industry. It is heavy bearing and very precocious, and is performing well from North Queensland to northern New South Wales. No work has been conducted on how this variety may be best managed.

Project objectives

We identified that custard apples, which are semi-deciduous and have some similar tree growth characteristic similar to temperate fruits, could be better trained to new improved systems than the standard vase systems which produces exceptionally large trees which are difficult to harvest.

This project aims to find the best method for managing KJ Pinks by comparing two new training systems, namely the Maroochy V trellis and the mechanically-pruned hedgerow system used in several other tree crops, with the standard open vase-trained trees, the current industry standard.

Three major training systems will be compared:

- Normal vase (400 trees per hectare)
- Maroochy (open Tatura) trellis (800 trees per hectare)
- Mechanically pruned hedgerow (600 trees per hectare)

MAROOCHY V TRELLIS TRIAL-ALSTONVILLE 2003-7

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Introduction

This was the first major observational trial of its type on custard apple trellising and has subsequently led to the adaptation and modification of the designs of later training systems established as part of this project in 2004.

Methods and materials

Site
This observational trial was set up in 2003 at a commercial farm in Alstonville, northern NSW. The site has a deep red krasnozem soil, which produces extremely vigorous trees.

Trellis design
QDPI&F collaborated with the Mr Phil Stacey in the design of the training system which we have subsequently named the Maroochy V trellis. The variety grown on the trellis was KJ Pinks. We have also assisted in the management of the training observation over the past 5 years.

The V-trellis is a support system constructed at 30° from the vertical giving an internal angle between the two supports of 60°. Each V-trellis supports two rows of trees 1.2 metres apart. The rows are running north-south. Within the rows, the trees are 4.5 metres apart. Walking along the centre of the V-trellis, the trees alternate to the left and the right in the two rows (i.e. are diagonally opposite, Figure 1). Adjacent V-trellises are 5.5 metres apart. With this spacing and some regard for the border of the netting structure, the planting is equivalent to about 750 trees per hectare.

There are 4 wires spaced 50 cm apart on each arm of the V-trellis. The trees are grown to a central leader at 30° from the vertical (i.e. parallel to the support) with the branches espaliered along the wires.

Total exclusion netting over the trees is supported by 28 tonne 8mm cables across the tops of the V-trellis support poles. The net extends down to 30 centimetres below the ground.

For comparison, a non-netted V-trellis system was planted at the same time adjacent to the trial netted block.

(a)

(b)

(c)

(d)

(e)

(f)

Plate 1. Maroochy V trellis at Alstonville. (a) net house construction with exclusion netting (b) young KJ Pinks with subleaders espaliered on V trellis (c) subleaders showing well-developed fruiting laterals (d) overall tree structure of 4 year-old trees (e) heavy fruit set on V trellis (f) very high quality KJ Pinks fruit

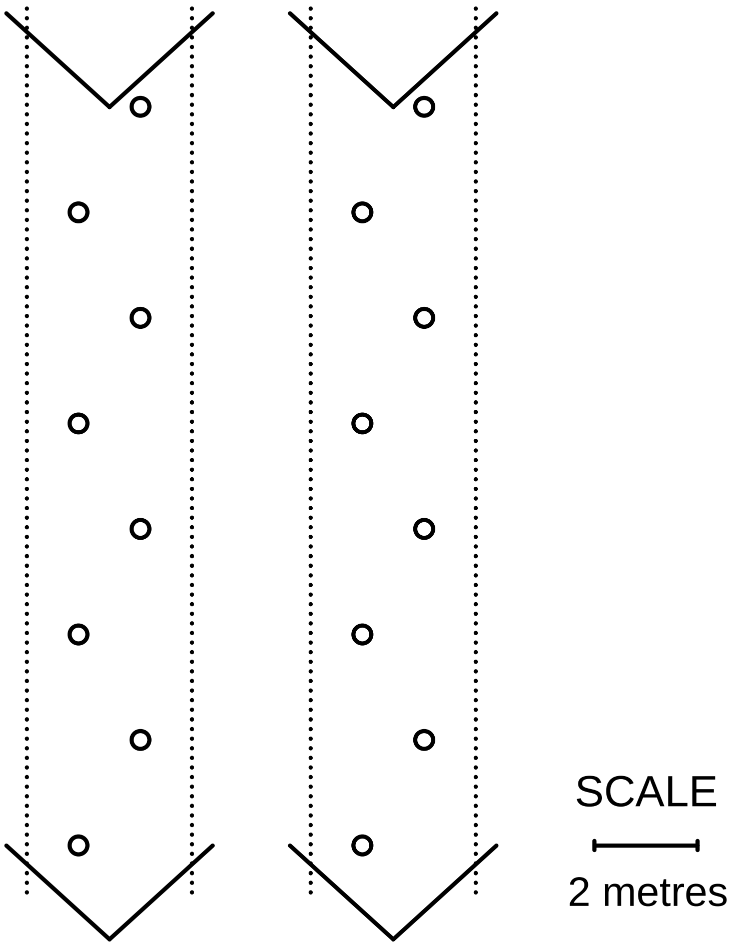

Figure 1. Design and layout of trellis system at Stacey Orchard, Alstonville

Orchard management

Pruning
Initial pruning to the espalier shape along the wires required fairly regular attention. Rubber 'Easi-ties' are used to tie the branches to the wires. These can be adjusted and removed. Full tree shape was established in approximately three years, with fruiting laterals kept short and well spaced along the main arms of the trellis trained trees. Any vigorous shoots growing vertically or from the main trunk between the wires were removed. Structural pruning was carried out in October 2007 producing well-lit tree canopies.

Tipping and stripping
In addition to the structural pruning, shoots were tipped and stripped. Four to six leaves at the end of each tipped shoot were left, while all leaves below this were

stripped to the bottom of the shoot. The advantage of this is that the flowers and fruit set due to the stripping are borne on stronger wood and are less likely to bend the branches or to sway.

Irrigation
Irrigation lines were positioned down the centre of each V-trellis. Trees were irrigated according to the soil moisture content, which is monitored using 'Soil Spec' tensiometers.

Humidity
Humidity was increased on hot, dry days in the netted block of trees by turning on the overhead sprinklers to assist pollination and fruit set.

Spraying
The only sprays applied to trees inside the netted enclosure were for caterpillars. Comparison trees outside the netted enclosure did not require any sprays for caterpillars but twice as may sprays were needed to control other pests.

Phenological and carbohydrate cycling data
Phenological and carbohydrate cycling data for this trial was collected by Dr Trevor Olesen and his findings are presented in a separate section of this report.

RESULTS

Effects of exclusion netting on the orchard environment

The average daily temperature for the first five months of 2007 was approximately 0.5 °C cooler under the net than outside the net. The daily maxima were about 2 °C cooler under the net, but the daily minima were similar (Figure 2).

The midday relative humidity was approximately 8% higher under the net (Figure 2).

There was approximately 15% less light under the net. Direct sunlight was reduced but scattered light was increased due to reflected light from the net. Therefore on sunny days, an increased amount of glare was experienced inside the netted enclosure compared to outside the enclosure.

Humidity is slightly higher under the netted enclosure and can be easily increased by turning on overhead sprinklers during the heat of the day when the weather is dry.

Soil moisture monitors have been placed inside and outside the netting. The soil moisture difference was still being evaluated.

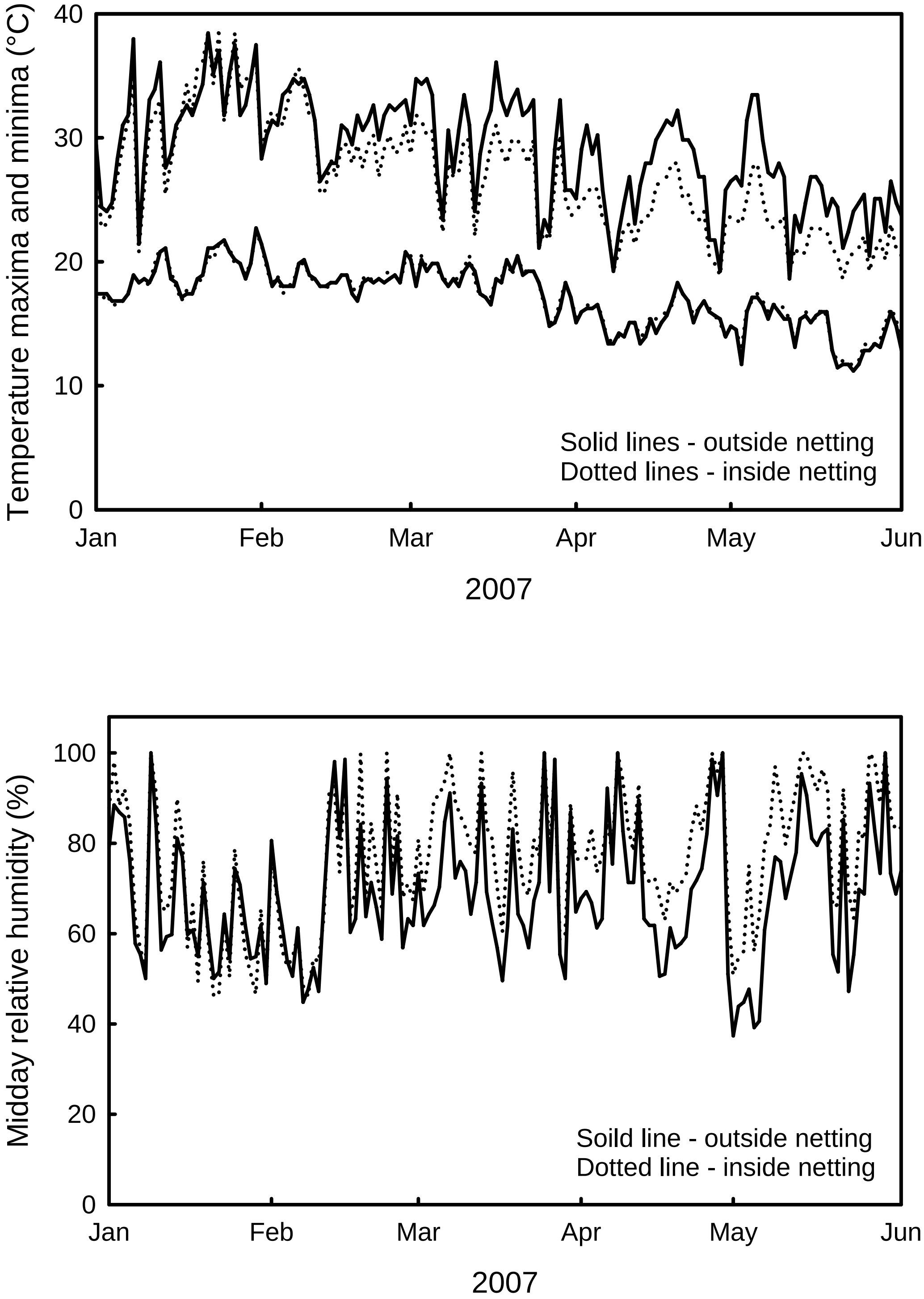

Figure 2. Daily temperature maxima and minima and relative humidity inside and outside the netting structure.

Light transmission

The cross-sectional light transmission survey from Alstonville shows the effectiveness of the V-trellis at increasing planting density, whilst keeping a good light interception regime (Figure 3). As expected, the light transmission rate is lower in the areas of the row obscured by leaves, shoots or fruit, but the transmission rates remained high down the centre of the row.

The mid-row light transmission rate was approximately equal to the inter-row light transmission rates. The lower light transmission on the eastern side can be easily explained as the measurements were taken mid-afternoon instead of during the middle of the day, resulting in the eastern arm of the row casting a wider shadow into the next row. This is merely an effect of the sampling time and therefore is inconsequential to the overall light interception effectiveness of the trellising system.

Growth

Although there is 15% less light under the net, the trees are more vigorous than the comparison trees outside the netted enclosure. During 2007, average shoot growth of 2.1 metres was recorded inside the netted enclosure compared to 2.1 metres outside the netted enclosure. The size of the leaves on the trees inside the netted enclosure were 20% larger compared to leaves sampled from the tress outside the netted enclosure.

The longest shoots to develop on the trees under the net during 2006/07 were 2.1 metres in length under the net, compared with 1.2 metres outside the net.

Pests and diseases

Fruitspotting bug, Queensland fruit fly, yellow peach moth and vermin were totally excluded from the netted block of trees. There was increased spider activity and for the first three years, a large build-up of cluster caterpillars, loopers and hairy caterpillars, necessitated regular insecticide sprays until the breeding cycle was broken. This year the caterpillar activity was considerably less. The caterpillar pupae which caused damage to the foliage may have come from out of the ground prior to nets being erected or another possibility is that moths were laying their eggs on the net and the caterpillars were falling into the netted area.

Ants have also been a problem by building nests in the holes of the trellis poles where the wire passes through. There are no ants on the control trellis outside the netted enclosure. This year saw a reduced ant activity inside the netted enclosure. Mealybug was also present but not in large numbers.

There has been no evidence of fungal diseases, even last year, when anthracnose ran rampant in the main custard apple block.

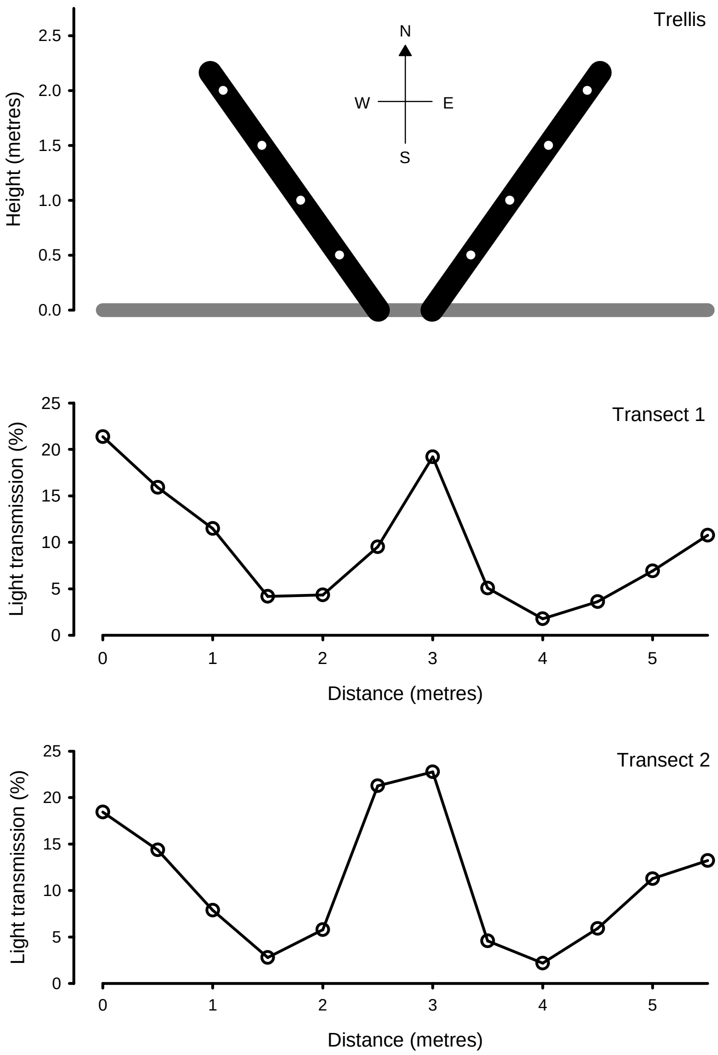

Figure 3. The transmission of light to the height of the lowest wire (50 cm above the ground) through trellised custard apple canopies under netting. Two transects were made at right angles to the trellis structure, from the middle of one alleyway to the middle of the next. The measurement were made mid afternoon on May 21, 2007.

Yield

Fruit were thinned, mostly to remove misshapen fruit. Harvesting on trellised trees was easier than for vase trained trees as fruit were highly visible and within easy reach from the ground.

In 2006, three-year old KJ Pinks trees averaged about three trays each under exclusion netting. By 2007, yields per tree under exclusion netting had nearly doubled to 6 trays per tree (Table 1). Compared with un-netted trees, yields on netted trees were about 40% higher, indicating that the netting had provided a favourable micro-environment for pollination and fruit set.

TABLE 1. *Yields on 4-year-old KJ Pinks trees on Maroochy V trellis at Alstonville in 2007*

Training system	Netting type	Trays per tree	Yield per tree (kg)	Estimated yield per hectare (tonnes)	Trays per hectare
Maroochy V trellis	No netting	4.2	27.3	20.5	3142
Maroochy V trellis	Exclusion netting	5.9	38.6	28.9	4413

We estimated that trees could potentially carry eight trays per tree at full maturity. Based on an average price of $25 per tray, maximum gross returns of $150 000 per hectare may be feasible (Table 2). For comparison, vase-trained trees planted at much lower densities would need to carry 16.2 trays per tree to give equivalent returns.

We suggest that although the establishment costs of the Maroochy V trellis system with exclusion netting would be much higher than an un-netted, vase trained orchards, the V trellis system is much easier to train, prune, harvest and spray. We suggest that labour cost associated with these practices would be about 30% less than for vase systems. More detailed studies are planned to calculate the economic benefits of the various training and netting systems.

TABLE 2. *Actual and predicted yield for Maroochy V trellis system under exclusion netting at Alstonville*

Tree age from planting	Yield and predicted yield				Estimated gross return per hectare*** ($)
	Trays per tree	Yield per tree (kg)	Estimated yield per hectare (tonnes)	Trays per hectare	
3	3.0	19.5*	14.6	2244	56100
4	5.9	38.9*	28.9	4413	110325
5	7	45.5**	34.0	5236	130900
6	8	52.0**	38.9	5984	149600

* actual yield,** predicted yield, *** assumes an average price of $25 per tray

Harvest period

Netted trees produced two harvest peaks presumably due to two flowering flushes compared with un-netted trees (Figure 4).

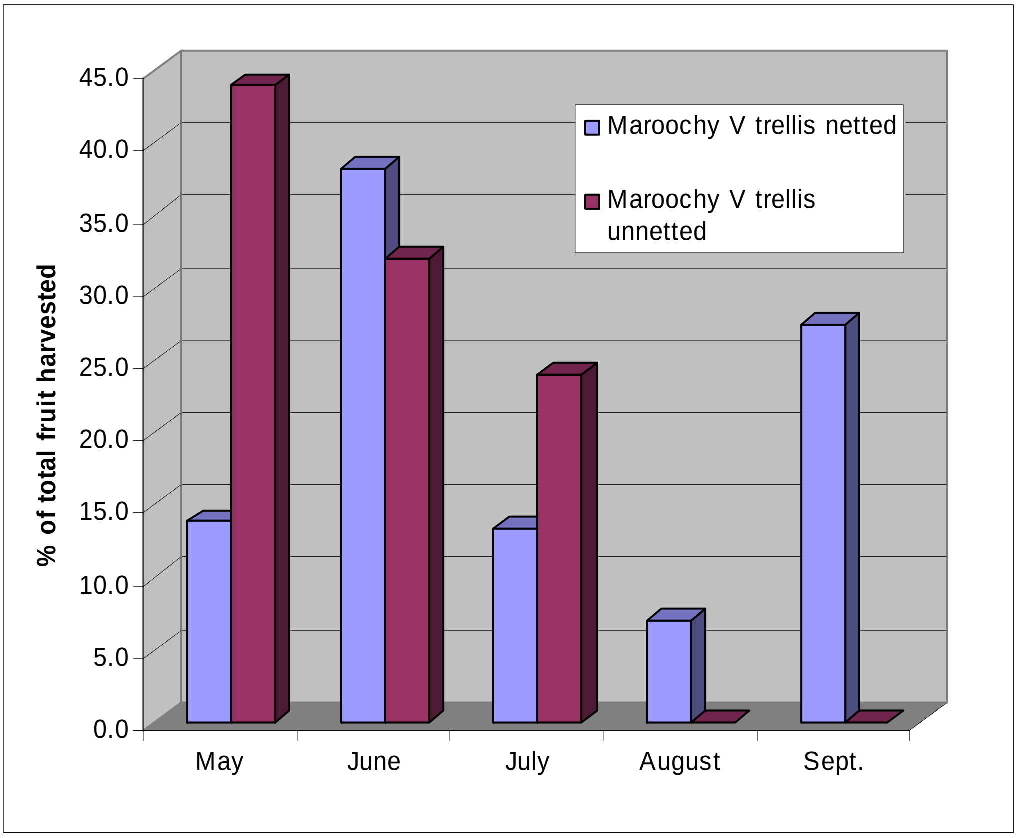

Figure 4. Effects of exclusion netting on harvest period of cv. KJ Pinks trained on Maroochy V trellis at Alstonville in 2007.

Fruit size grades

Fruit quality under exclusion netting is higher because of the exclusion of birds and grazing insects, and a considerable reduction in damage from wind rub. About 77% of the fruit under exclusion netting was size count 15 and larger. Of these, about 15% of the fruit were extra large size count 9 and less. The fruit under the netting is also less prone to fruit splitting. Fruit splitting can be a big problem on the trellis trained trees during cold weather if the canopies are pruned too sparsely.

Compared with hedgerow trees of similar age and crop load at Glasshouse Mountains, netted Maroochy V trellised trees at Alstonville produced a greater number of larger fruit (lower fruit counts) giving a four-fold reduction in bulk fruit (Figure 4).

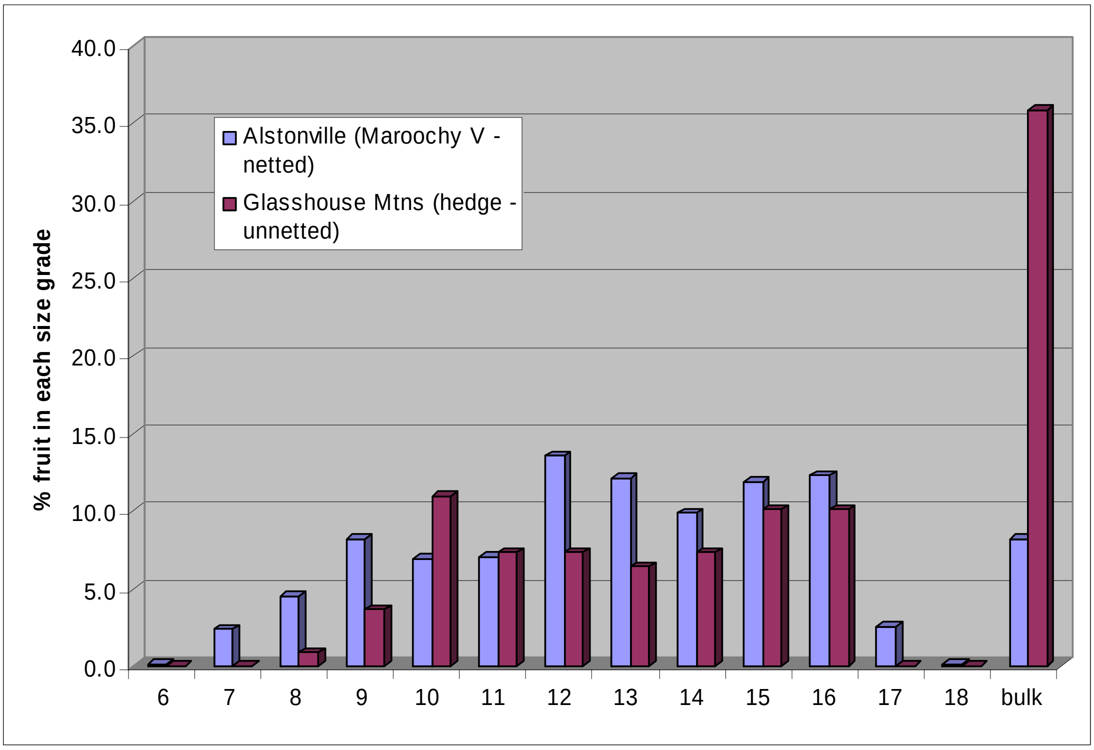

Figure 5. Comparison of fruit size grades for cv. KJ Pinks grown on Maroochy V-trellis with exclusion netting at Alstonville and a hedge system un-netted at Glasshouse Mountains. Trees are of similar age and crop load.

Late summer pruning of Maroochy V trellis

Custard apple is unusual in that, if you prune a branch and do not remove a leaf from behind the pruning cut, the branch will not develop a new shoot.

We hypothesized whether this response by individual branches would still hold if all the branches on the tree were pruned in a similar fashion. In January 2007, this was carried out on several Maroochy V trellis trees. No new shoots developed after pruning, and only few new shoots by May 2007. These shoots only appeared where leaves had been damaged or removed. By May 2007, the trees inside the netted enclosure that hadn't been pruned were four metres high, while those that had been pruned were 2.7 metres high (Figure 5). Outside the netted enclosure, the non-pruned and pruned control trees were 3.4 and 2.5 metres high, respectively. There is unlikely to be substantial regrowth until the leaves drop in the spring.

Clearly, hand pruning all branches on every tree is impractical. Our next step is to see how this might be applied on the trellis system. For example, in northern NSW branches are often tipped and stripped in January to promote late fruit. There may be a number of advantages in just tipping the branches at the very tops of the trees, while tipping and stripping the branches lower down.

Figure 5. Foreground: effects of shoot tipping without leaf stripping showing little or no regrowth. Contrast background: untipped shoots showing excessive shoot growth.

DISCUSSION

Advantages of trees grown under netting:

- No fruit fly, fruit spotting bug, possums, birds, rats, flying foxes, etc.
- Once caterpillars were controlled, spraying was virtually eliminated.
- No wind damage to limbs and less marks on fruit, due to fruit rub.
- Hail protection.
- Humidity can be increased easily in dry weather via overhead sprinklers.
- There may also be a reduced need for irrigation due to less evaporation.
- Increased production due to reduction in fruit losses due to quality defects.

Advantages of growing on the V trellis:

- Ease of harvesting, therefore labour costs are reduced.
- Ease of pruning and easy to teach new employees.
- Ease of spraying – more effective spray coverage.
- Less damage to trees (limb breakages etc.) and fruit from wind, and people movement during routine orchard maintenance and harvesting operations.

Disadvantages of growing under netting:

- Initial cost and maintenance.
- Initial caterpillar problems.
- Increased ant activity.
- Increased spider activity (scary for those people with arachnophobia).

Disadvantages to growing on V trellis:

- Initial cost and maintenance.
- Dedication to initial training development.

OBSERVATIONS ON PRUNING, CARBOHYDRATE CYCLING, AND AXILLARY BUD RELEASE IN CUSTARD APPLE GROWN ON MAROOCHY V-TRELLIS – ALSTONVILLE 2006-7

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Abstract
Here we examine the control of axillary bud release in custard apple, and how it might be used to advantage in tree training. We show that custard apple flowering is probably terminal/sub-terminal, not extra-axillary as previously thought, and that the apparent continuation of the shoot beyond the flower is most likely a sympodial branch instead.

We confirm the strong inhibitory effect of leaves on axillary bud release and show that summer decapitation of all branches on a tree can arrest canopy development until the following spring, but at some cost to yield. The cost to yield appears to be from the smaller canopy and consequent higher carbon limitation to growth.

Netting trees increased vigour, possibly because of increased relative humidity beneath the net. The greater vigour had little effect on yield.

Introduction
Custard apple (cherimoya *Annona cherimola* Miller x sugar apple *A. squamosa* L.) is one of the most vigorous horticultural trees. Under good conditions, new shoots can grow more than three metres in a season. Growers need a canopy management strategy, but we are hampered in the development of such a strategy by a lack of understanding of the basic botany of the plant. Here we look at the control of axillary bud release, especially in relation to flowering and branch decapitation.

The flowers of custard apple are borne singly or in small clusters, usually on the new shoots that develop from axillary buds following leaf abscission, but sometimes from older nodes (Moncur, 1988). Sometimes the new shoots are pure inflorescences, but often the flowers are borne on leafy shoots a few nodes away from the base. Superficially, the flowers on leafy shoots appear to be extra-axillary (i.e. borne opposite the leaves; Venkataratnam, 1959; Thakur and Singh, 1965; George and Nissen, 1991; Fig. 1) but in the micrographs of developing custard apple flowers presented by Moncur (1988) the flowers seem to be apical. This raises the possibility, examined here, that the flowers on the leafy shoots are terminal, not extra-axillary, and that the apparent continuation of the stem beyond the flower is instead a sympodial branch. Such branching would not be obvious because there are several buds in the axil of each leaf, and these buds are hidden by the base of the petiole.

Custard apple is semi-deciduous, losing its leaves in the spring. Leaf abscission is followed shortly afterwards by axillary bud release and the development of new shoots. New shoot development at other times of year is uncommon and associated with leaf loss caused by external factors. Interestingly decapitating select branches within a canopy over late spring and summer, without removing leaves from below the pruning cut, does not lead to axillary bud release from the branches in the current season (George *et al*. 2001). Thus leaves appear to have a powerful inhibitory effect on bud release. Here we show that if all branches on a tree are decapitated in summer, the expansion of the whole canopy can be arrested for many months.

Arresting extension growth lowers whole tree carbon assimilation but makes proportionately more of the assimilated carbon available for non-extension growth, so the effect on the growth of other organs is difficult to predict. Here we show that fruit development is slower in trees with arrested extension growth and that this corresponds with lower dawn concentrations of non-structural carbohydrates, indicative of greater carbon limitation to growth.

Materials and methods

Morphology

'African Pride' custard apple shoots were collected from the orchard at the Centre for Tropical Horticulture, Alstonville (28.9°S, 153.5°E). The shoots were dissected then photographed using an Olympus SZ60-CTV stereo microscope and an Olympus C-5050 digital camera.

Pruning trial

The pruning trial was conducted on 'KJ Pinks' custard apple trees grown at Alstonville in northern NSW (28.9°S, 153.4°E). The trees were trained onto either the east or west arm of north-south 'V-trellises'. The east and west arms were 30° from the vertical (i.e. there was a 60° internal angle). Two trellises were used: one within a total exclusion netting shade-house that transmitted ca 85% of full daylight; the other immediately outside the shade-house to the east. More details on the orchard can be found in Stacey and Olesen (2007).

The trees on the trellises were three-years-old and a little over 2 m high following a severe structural prune in early September 2006. The trees inside the netting had occupied most of the allotted space along the trellis wires, but there were still substantial gaps along some of the wires outside. Eight trees were chosen for study, four on each trellis. Stems of young branches were sampled for carbohydrate analyses (see below) every three weeks from 13 September 2006 until 2 May 2007. The branches for sampling were selected and randomised on 11 September 2006.

Relative light levels beneath the canopies (see below) were taken at irregular intervals from 17 November 2006 until 21 May 2007.

Two trees on each trellis were left as controls while the other two were pruned on 16 January 2007. Pruning involved the decapitation of every branch. The severity of pruning varied with branch length: the longest branches were cut approximately 20 cm back from the tip while the shortest branches were cut just behind the tip.

On 21 May 2007 the three longest branches were cut from each tree and each branch separated into leaves and stem. The tenth and eleventh leaves from the apices on the control branches were placed apart and photocopied for the estimation of leaf area and, ultimately, specific leaf weight. All the material was dried to constant weight at 80°C and the constant weights were recorded.

Total fruit numbers were counted on 21 May 2007. Fruit was harvested at irregular intervals from 9 April 2006 until 6 August 2007. Fruit of a commercial size and shape were weighed, regardless of whether the fruit were split or not. The weighed fruit accounted for 93% of fruit on the trees.

General observations were made on the trees until 14 September 2007.

Carbohydrate analyses
One branch was sampled from each tree at each sampling time. From each branch a short length of stem, 5-10 mm in diameter and a few centimetres in length, was excised at dawn and oven dried to constant weight at 80°C. The stem was then ground to powder using a cyclonic mill with a 1 mm sieve (UDY Corporation).

Total non-structural carbohydrates (TNSCs) were extracted by placing 100 mg of powder into 17 mL of ethanol:water (1:16); adding 40 μL of high temperature stable amylase solution and incubating firstly in a boiling water bath for 12 minutes then in an 83°C water bath for 1 hour; cooling to room temperature with gentle agitation; adding 2.56 mL of citrate buffer (7.37g.L^{-1} sodium citrate dehydrate, 3.8 g.L^{-1} citric acid, pH 5) and 0.4 mL of amyloglucosidase (59.9 units.mg^{-1}) and incubating at 55°C for 1 hour; again cooling to room temperature with gentle agitation; then spinning out the residue at 3000 rpm.

Water soluble carbohydrates (WSCs) were extracted by incubating 100 mg of powder in 20ml 0.2% w/w benzoic acid solution with gentle agitation at room temperature for 1 hour; then spinning out the residue at 3000 rpm.

Both the TNSC and WSC extracts were analysed by the anthrone method. For the TNSC analyses, 0.4 mL of supernatant was added to 0.6 mL of ethanol:water (1:16) to give the 1 mL sample. For the WSC analyses, the 1 mL sample was undiluted supernatant. 5 mL of the anthrone reagent (760mL sulphuric acid, 330mL of water, 1g of thiourea and 1g of anthrone) was added to the 1 mL sample while the sample was being spun on a vortex mixer. The mixture was then incubated in a boiling water bath for 3 minutes; transferred to an ice-water bath for 10 minutes; brought back to room temperature; and measured at 620 nm in a spectrometer using a 10 mm cuvette. The standards were 0-500 mg.L^{-1} D(+)glucose in either ethanol:water (1:16) or 0.2% w/w benzoic acid solution. To account for background colour, samples were also run using a sulphuric acid reagent (760mL sulphuric acid, 330mL of water and 1g of thiourea) in lieu of the anthrone reagent.

Relative light transmission
Relative light transmission was estimated using a LI-COR LAI 2000 fitted with a view restrictor that limited the instrument to 11° of azimuth. The lens was oriented south. The above canopy measurements were taken from the top of a ladder adjacent to the trellises, approximately 3 m above the ground. The below canopy measurements were taken 0.5 m above the ground, beneath the uppermost trellis wires, which run 2 m above the ground, with the trunks of the trees approximately 1.5 m to the east or west.

The transmission values calculated from the five sensors below the lens were weighted according to the proportion of the sky vault each sensor measured, then summed.

Statistics
The data was analysed in *SigmaStat* (Jandel Corp., San Rafael, CA) using the provided statistical package or writing new code based on the mathematics in Sokal and Rohlf (1995). The exponential curves in Fig. 5 are of the general form $y = a.e^{a.x} + b$ where y and x are variables and a is a shape parameter and b the asymptote parameter, and were significant ($P < 0.001$). The other curves in Fig. 5 are horizontal lines (means) because no significant linear regressions were found ($P > 0.100$). The sinusoidal curves in Fig. 6 are of the form $y = a + b.\sin(c.x - d)$ where y and x are variables and a, b, c and d are parameters related to vertical displacement, amplitude, period and phase, respectively. $P < 0.001$ for the sinusoid with a broken line; $P = 0.018$ for the sinusoid with a solid line. One of the straight lines in Fig. 6 is a mean because no significant regression was found ($P > 0.100$) while the other was significant at $P = 0.046$.

Results

Terminal/subterminal flowering and sympodial branching
Custard apple cultivar 'African Pride' typically has three axillary buds surrounded by the leaf petiole except for a small opening on the adaxial surface (Fig. 2).

Where there is a flower opposite, however, there are only two axillary buds and the opening on the adaxial surface is much larger (Fig. 3), indicating that flowering was terminal (or possibly subterminal, assuming abortion of the apex, although we found no macroscopic evidence of this, e.g. in Fig. 1, and the developing flowers in the custard apple micrographs of Moncur (1988) appear to be apical), and that the apparent continuation of the shoot axis was a new branch. There is further support for this in the 'wedge' contours of the bark at same node (Fig. 3).

The flower is sometimes directly opposite the leaf (Fig. 3, lower photograph), but more often slightly below (Fig. 3, upper photograph). The latter cases probably result from stem extension that moves the leaf from initially below (or parallel to) the terminal bud at floral initiation, to a position above.

This accounts for the isolated flowers on the leafy shoots. Accordingly, flower clusters probably arise from a combination of terminal and subterminal, possibly axillary, meristems (Fig. 4).

General phenology of trellised 'KJ Pinks'
The 8 trees were severely pruned in September 2006 while still in leaf. Leaf abscission followed.

When the trees were viewed on 17 November 2006 the trees inside the shade-house had shed all leaves and had new shoots up to 300-350 mm in length. The trees outside the shade-house had shed most leaves and had new shoots up to 150-200 mm in length.

By 28 December 2006 the trees inside the shade-house had fruit up to ca 30 mm in diameter, while the most advanced fruit outside the shade-house were just beyond anthesis.

The first harvest was on 9 April 2007 inside the shade-house and on 8 May 2007 outside.

Growth of trellised trees

Towards the end of the growing season on 21 May 2007 the shoots inside the shade-house were much longer than those outside (Table 1; $P < 0.001$). This resulted in the trees inside the shade-house being taller than the trees outside (Table 1) because all the trees had been pruned to approximately the same height at the beginning of the season.

The trees that were pruned on 16 January were almost entirely arrested until leaf drop the following September. The few shoots that did come away in the intervening period were associated with leaf drop.

The mature leaves on the shoots inside the shade-house had broader leaf areas (Table 1; t-test $P = 0.010$) and higher specific leaf weights (Table 1; rank sum test $P = 0.007$) than the leaves outside.

There were similar numbers of fruit on the trees inside and outside the shade-house and on the pruned and control trees (Table 2; two-way anova $P > 0.100$).

As mentioned above, first harvest was earlier inside the shade-house than outside. The general visual impression was that the fruit on the control trees ripened sooner than the fruit on the pruned trees.

Fruit size was similar inside and outside the shade-house (Table 2; two-way anova $P > 0.100$) but greater on the control trees than on the pruned trees (Table 2; two-way anova $P = 0.016$).

There was substantial fruit splitting (Table 2). Pruning increased splitting while shade-house cover decreased it, based on a three-way interaction effect between splitting, pruning and shade-house cover (G-statistic $P = 0.011$).

Relative light transmission

Relative light transmission measurements were made under the tallest parts of the canopies. Transmission levels at these locations are intermediate with respect to the variation in transmission through different parts of trellised custard apple canopies (Stacey and Olesen 2007).

Transmission diminished exponentially as the new season’s shoots developed from late spring (Fig. 5). Transmission was lower inside the shade-house than outside, consistent with the observation above that the shoots inside the shade-house emerged sooner and achieved a greater size. In terms of the fitted curves, there was no difference in the shapes of the curves (T’-method $P > 0.100$) but the curve for transmission inside the shade-house had a smaller minimum transmission asymptote (T’-method $P < 0.050$).

Transmission values for the trees pruned on 16 January were essentially constant following pruning, consistent with the negligible post-pruning shoot development noted above, although the control trees were approaching their minimum transmission asymptotes over the same period (Fig. 5). A two-way anova of transmission values on the final measurement date (21 May) found pruning (P = 0.034) and shade-house (P = 0.020) effects.

Note that the lower relative transmission values inside the shade-house would be even lower in absolute terms because of the attenuation of light by the netting to about 85% full daylight.

Non-structural carbohydrates

Stem TNSCs declined exponentially following the spring pruning (Fig. 6). The decline was similar inside and outside the shade-house (T'-method P > 0.100 for both shape and minimum TNSC asymptote). The stem TNSCs for the pruned trees were relatively constant, similar inside and outside the shade-house but lower than the control trees over the same range (two-way ANOVA based on the tree means over the range P < 0.012).

Stem WSCs varied in a sinusoidal fashion both inside and outside the shade-house (Fig. 6). The amplitudes and periods of the curves were similar (T'-method P > 0.100 for parameters *b* and *c*) but there were suggestions of differences in the phases and upward displacements of the curves (T'-method 0.05 < P < 0.100 for parameters *a* and *d*) indicating that the trees inside the shade-house had generally higher WSC concentrations than those outside the shade-house, and minimum and maximum concentrations earlier in the season.

Comparisons of stem WSCs between treatments is difficult because of confusion over what model to apply to all curves (Fig. 6). A two-way ANOVA of concentrations on the final sampling date (2 May) found a pruning (P = 0.016) effect.

Discussion

Flowering

On the available evidence (Figs 1-4 and Moncur 1988) custard apple flowering is terminal/sub terminal.

Why then is flowering mostly, if not exclusively, a phenomenon of early shoot development? Rephrasing this, why are apices often florally determined during early shoot development but vegetatively determined later? There is no answer, but such a strong, simple developmental dichotomy, coupled with the ease with which flowers can be forced by tipping and stripping shoots, makes custard apple a good candidate as a model tree for the study of flowering.

The control of branching

Decapitation of large shoots back to mature leaves seldom if ever leads to axillary bud release unless at least one leaf has been lost from behind the pruning cut (Table 1). This indicates a more powerful role for leaves in the regulation of axillary bud release in custard apple than in other tree species.

The sub-petiolar location of the axillary buds may necessitate this because of the mechanical stresses that would be imposed on the petioles if axillary buds were to come away while the leaves were still attached.

Axillary bud release can occur without leaf abscission, as in the sympodial branching that often accompanies flowering (Figure 3), but it seems that such release needs to be initiated before the leaf has fully developed.

The branching of leafy shoots is tends to be restricted to early shoot development.

After spring leaf abscission there is a largely synchronised wave of new shoot development. Custard apple shoots grow continuously, in contrast to the recurrent flushing habit of many sub-tropical trees (e.g. avocado, lychee and macadamia; Olesen 2005), but the spring wave of new shoots and flowers might provide some of the putative ecological benefits of recurrent flushing (e.g. satiating insects that feed on immature tissue, such as fruit spotting bug on cashew Peng *et al*. 2005).

The control of leaf abscission is unclear, but there is a large annual cycle in starch concentrations that peaks in spring (George 2000), and anecdotal evidence that carbon sinks (e.g. fruit) delay abscission, that point to some role for carbohydrate feedback.

Effects of netting

Growing trees beneath netting seemed to increase vigour: the trees inside the shade-house had higher leaf areas and higher specific leaf weights than those outside, and longer shoot lengths, much longer than is likely to be accounted for by the earlier bud release (Table 1). Relative humidity, the midday values of which were 8% higher on average beneath the netting from 1 January to 1 June 2007 (Stacey and Olesen 2007), seems to be the major physical factor responsible for the difference in vigour given that custard apple stomatal conductance is highly sensitive to changes in relative humidity in the range 70-100% (George *et al*. 1990). Higher stomatal conductance is correlated with higher carbon assimilation (George and Nissen 2002), and the higher dawn levels of stem WSCs in the trees under the netting may have been a reflection of this (Fig. 6). Larger vapour water deficits have been shown to slow the growth of custard apple (George and Nissen 1988). The lower light levels and slightly cooler temperatures (0.5°C lower mean temperature from 1 January to 1 June 2007; Stacey and Olesen 2007) beneath the netting are unlikely to have contributed much to the effect.

The differences in vigour are unlikely to be related to differences in TNSCs at the beginning of the season. Changes in stem starch tend to track changes in starch in other parts of the tree, although the absolute concentrations vary between tissues (George 2000). Stem TNSCs declined very gradually over summer and autumn, and the rates of change were so small that the relative contribution of TNSCs to carbon for new growth is likely to have been very low (Olesen *et al*. submitted). Most of the carbon for new growth is likely to have come from current photosynthate.

The differences in vigour had little effect on yield (Table 2). The fruit on the trees under the netting were less prone to splitting, possibly because the fruit was more protected against dehydration.

Whole tree branch decapitation

Decapitating all the branches on a tree in January essentially arrested canopy expansion until the following September. Thus the prodigious vigour of custard apple is remarkably easy to control. This makes the tree very amenable to training to trellises, especially some of the more recent varieties, such as KJ Pinks, that naturally set high numbers of fruit.

However, decapitating all the branches caused dramatic and sustained reductions in the levels of stem TNSCs and WSCs (Fig. 6). The reductions probably indicate increased carbon limitation to growth (Olesen 1995) caused by the decrease in canopy size and consequent decrease in light interception (e.g. the higher light transmission in Fig. 5) consistent with the argument above that much of the carbon for new growth was coming from current photosynthate.

There was further evidence for increased carbon limitation to growth following the decapitation of all branches in the lower harvest weights of the fruit of the pruned trees (Table 2). Interestingly, George *et al*. (2001) found that when they decapitated only a few branches within a canopy, the subsequent harvest weights of fruit on those branches increased. Combining their observations with ours, it appears that branch decapitation can increase fruit weights locally within a canopy but only if the number of branches pruned is not so great as to compromise the overall carbon balance of the trees.

Acknowledgements
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Fig. 1. Typical flowering habit of custard apple, with the flower apparently (but not truly, see text) opposite one of the alternating leaves.

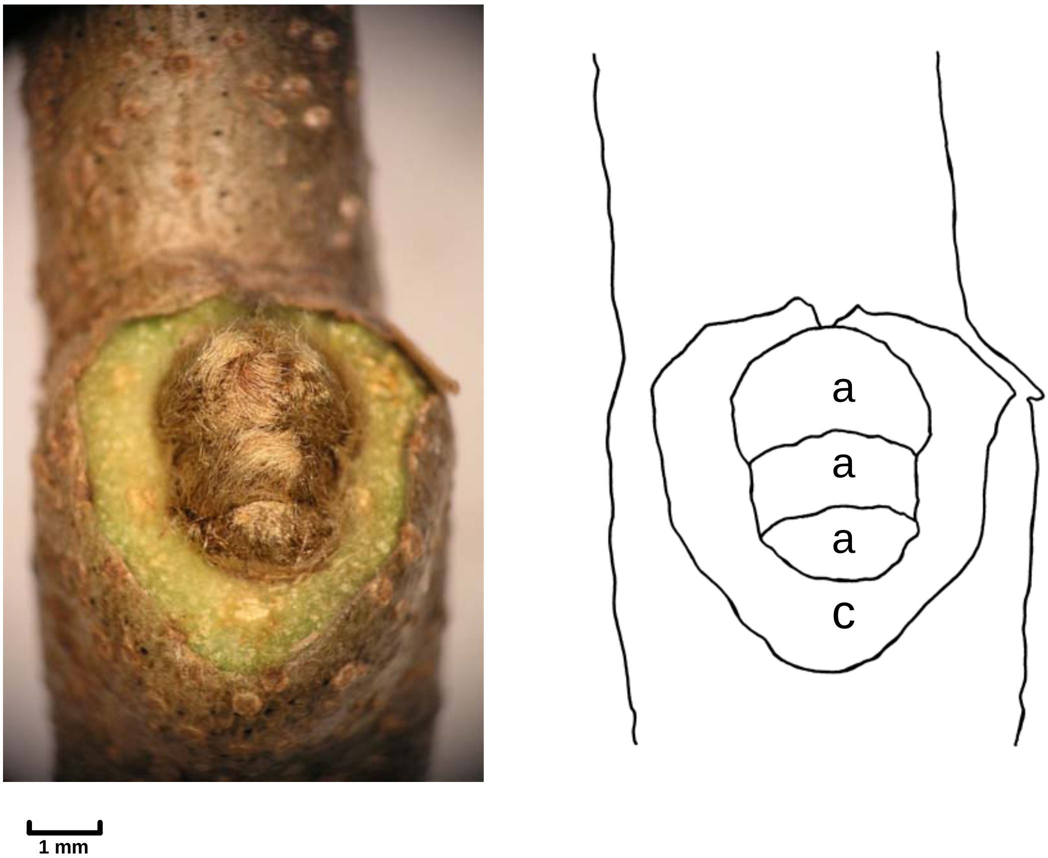

Fig. 2. There are three axillary buds at each leaf node on vegetative branches. The diagram alongside the photograph highlights the position of the axillary buds (a) and the leaf excision scar (c).

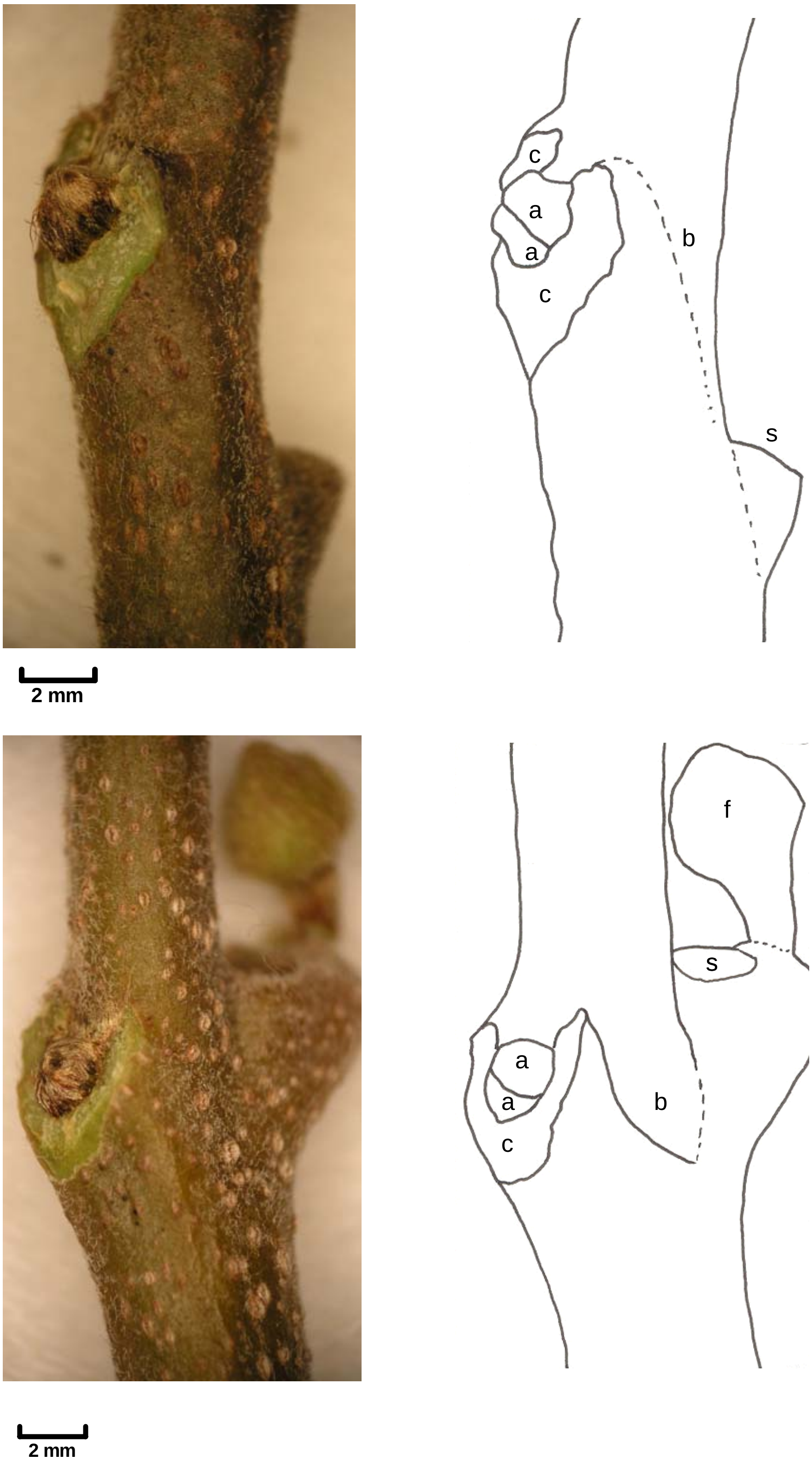

Fig. 3. Two examples of putative terminal/subterminal flowering in custard apple (f for floral bud, s for flower scar on the diagram of the photograph) with further shoot extension by sympodial branching, evidenced by only two axillary buds (a) in the adjacent leaf, the greater distance separating the ends of the leaf scar (c) than in Fig. 2, and the 'wedge' contour of the bark (b) where the branch meets the supporting stem.

Fig. 4. Clusters of custard apple flowers.

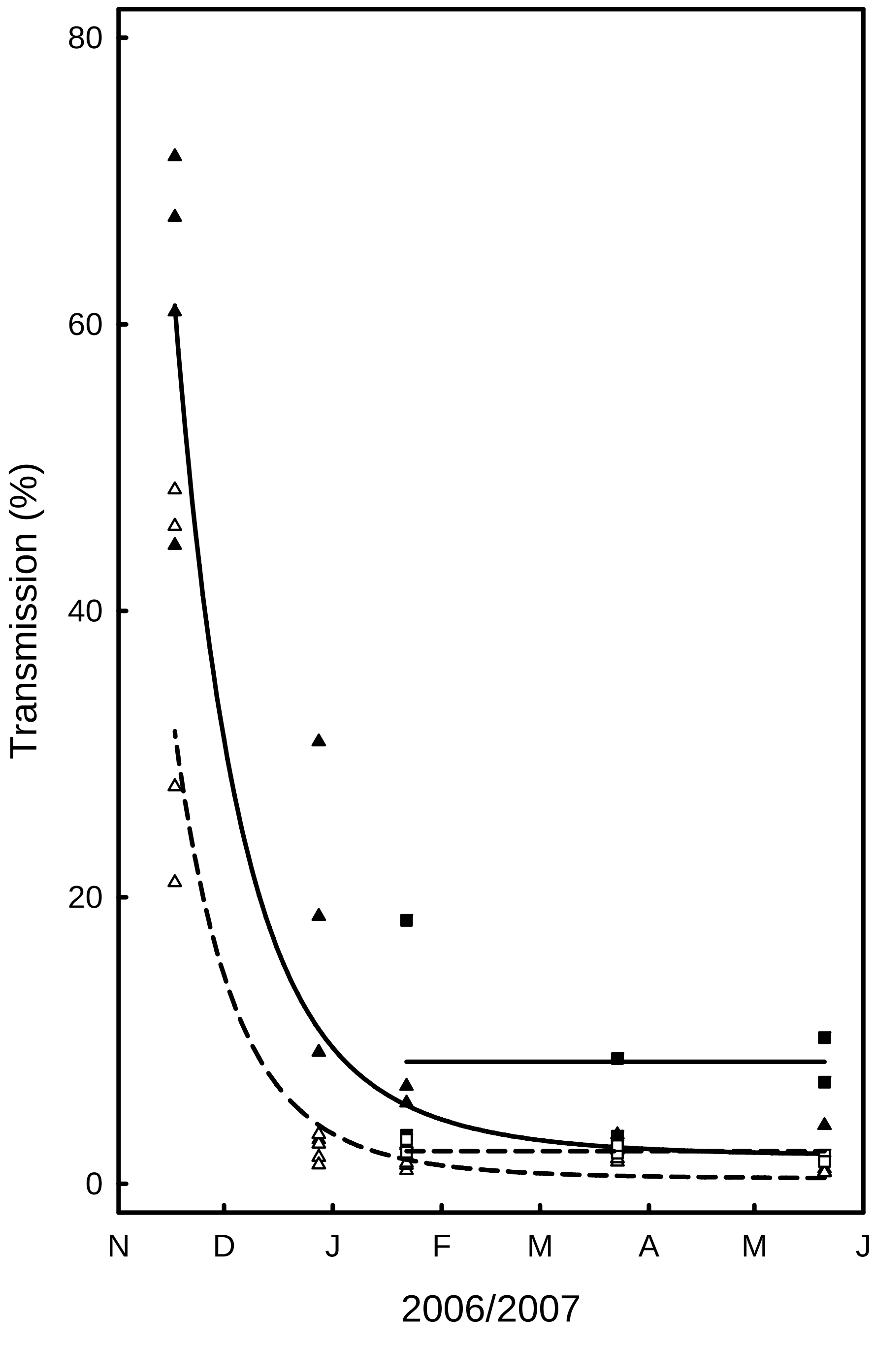

Fig. 5. Light transmission through a standard segment of the trellised 'KJ Pinks' canopies. See text for more details. Upper dashed line and open squares, the pruned trees inside the shade-house; lower dashed line and open triangles, the control trees inside the shade-house; upper solid lines and closed squares, the pruned trees outside the shade-house; lower solid lines and closed triangles, the control trees outside the shade-house.

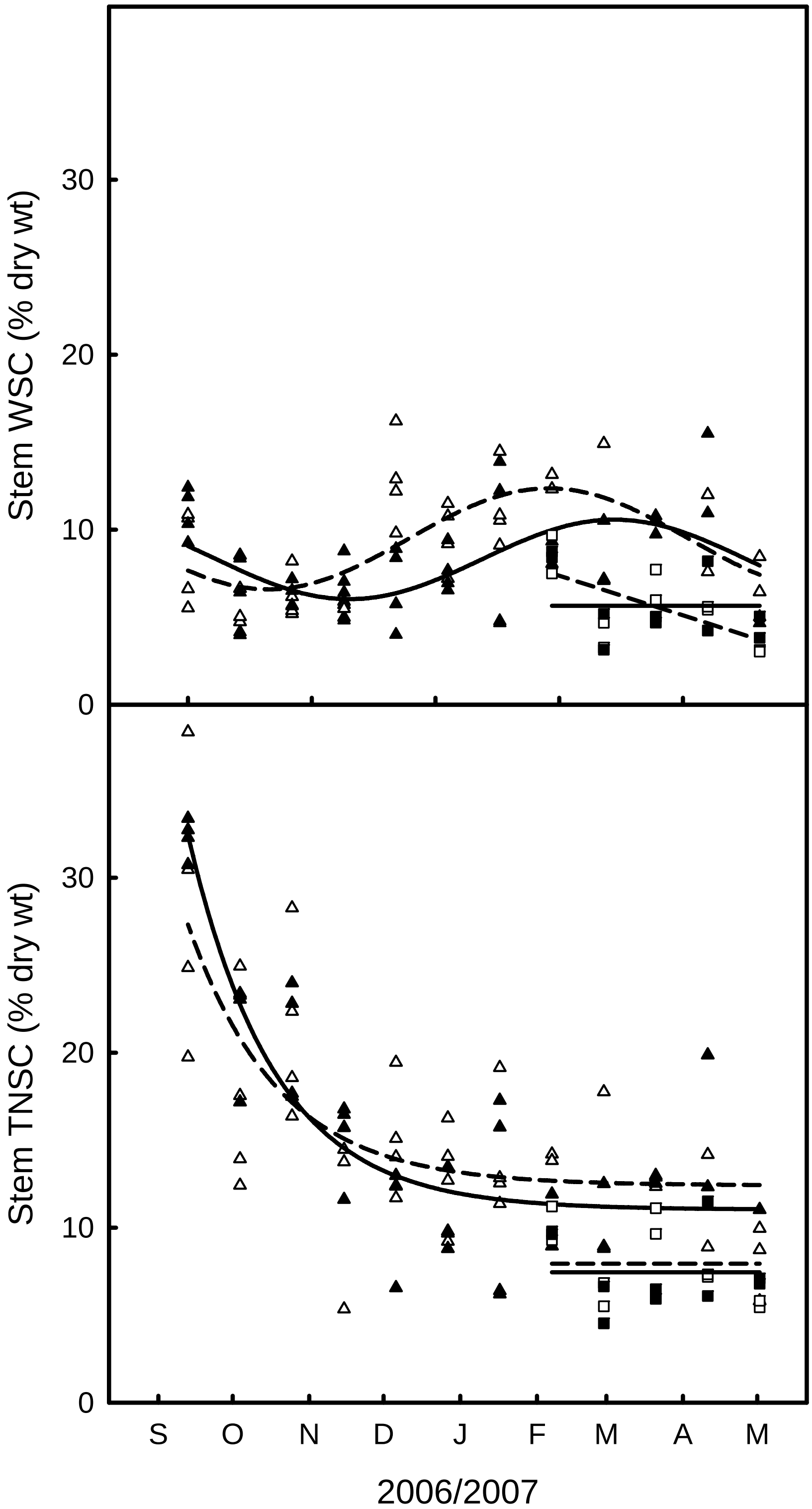

Fig. 6. Dawn levels of TNSCs and WSCs in trellised 'KJ Pinks'. Upper dashed line and open triangles, the control trees inside the shade-house; lower dashed line and open squares, the pruned trees inside the shade-house; upper solid lines and closed triangles, the control trees outside the shade-house; lower solid lines and closed squares, the pruned trees outside the shade-house.

Table 1. Canopy characteristics of trellised 'KJ Pinks' based on 3 shoots per tree and 2 leaves per shoot. The pruned trees had all branches decapitated on 16 January 2007.

	Tree height (m)		Longest shoot lengths		(m)	(se)	Leaf area (m^2)		Specific leaf weight ($g.m^{-2}$)	
			mean	(se)	mean	(se)	mean	(se)	median	(max, min)
	Pruned	Control	Pruned†		Control		Control		Control	
Inside netting	2.8	4*	0.52	(0.09)	2.35	(0.09)	0.0245	(0.0012)	124	(128, 116)
	2.6	4	0.47	(0.02)	1.91	(0.05)	0.0215	(0.0005)	111	(113, 106)
Outside netting	2.3	3.4	0.38	(0.02)	1.07	(0.05)	0.0197	(0.0009)	108	(150, 88)
	2.7	3.3	0.40	(0.07)	1.37	(0.01)	0.0211	(0.0004)	104	(113, 97)

* highest branch recurved against the netting
† pruned branches with no subsequent regrowth

Table 2. Yields of trellised 'KJ Pinks'.

	Fruit number		Fruit weight (g)				Fruit split (%)	
			median	(max, min)	median	(max, min)		
	Pruned	Control	Pruned		Control		Pruned	Control
Inside netting	107	93	370	(1480, 100)	540	(1330, 100)	8	2
	95	94	400	(880, 170)	485	(1190, 130)	13	5
Outside netting	81	73	420	(850, 150)	520	(1070, 150)	27	1
	82	97	310	(940, 150)	405	(1450, 150)	56	8

QUEENSLAND AND NSW REGIONAL TREE TRAINING TRIALS – 2004-2007

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INTRODUCTION

Based on the preliminary observational trials on new training systems (palmette and V trellis) conducted at Maroochy Research Station between 2001-2004, regional observational trials on new training systems compared with the standard vase system were setup in 2004. The objective of this experiment was to compared the productivity and light interception effectiveness of three types of training systems in three locations throughout the eastern Australian custard apple growing regions (from north Queensland to northern NSW).

MATERIALS AND METHODS

Training systems

Trials were set up on three tree training systems:

- Vase (standard) - 300-400 tree per hectare
- Hedge – 600 trees per hectare) and mechanically pruned
- Maroochy V trellis - 800 trees per hectare

The variety KJPinks was selected for the trials because of its high fruit setting ability.

Open vase system
The open vase system is the basic free-standing tree form (Plate 1a). Because it has no man-made structural requirements, it is the cheapest system to set up. However, harvesting and maintenance of vase trees is more difficult and costly due to their large size, and this sometimes requires the use of ladders. As vase trees grow to large sizes, they are planted in low densities of about 200-300 trees per hectare and return 12-18 tonnes of fruit per hectare. Foliar light interception is often very low (<5%) which may negatively affect fruit quality via shading (George, 2001).

Hedgerow
The hedge (or hedgerow) system is essentially a linear version of the vase system (Plate 1b), where vase trees are planted in rows. An example orchard may have 4.5 m between trees and 6 m between rows. The tree spreads out along the row until it shares space with the adjacent tree, essentially forming a hedge. With the uniformity of tree spacing and dimensions in hedgerows, trees can be mechanically pruned by a vehicle/machine travelling along the inter-row. This reduces harvesting and hand

maintenance costs by 30-40%. Hedges are planted at higher densities, potentially reaching 500 trees/ha.

V-trellis system

The V-trellis system maximises tree density by staggering tree positions to alternating sides of the row with shorter spacing (Plate 1c). For example, with 5m between rows and 1.5 m between trees, this system allows 1333 trees to be planted per hectare. Tree sub-leaders are trained to a horizontal espalier system, which is angled outwards from either side of the row at 30° from the vertical. The V shape has enough space to allow walk-through picking and maintenance from the middle of the row. The angled design also helps maximise the sunlight interception despite the higher tree density. While costly to set up, this system is the most efficient in terms of space, and it is the easiest to prune and harvest. This increased efficiency should reduce operating costs in the long term.

Row systems are the most effective when planted in the in North/South orientation. This allows sunlight to reach all the trees throughout the day while minimizing inter-tree shading effects.

(a)

(b)

(c)

Plate 1. The three training systems used in the regional trials at Alstonville, Yeppoon and Atherton. (a) Standard vase (b) hedgerow (c) Maroochy V trellis. Trees are about 18 months old.

Sites

Sites were selected to represent three distinctly different climatic regions. These sites were:

- Atherton in north Queensland,
- Yeppoon in central Queensland,
- Alstonville in northern New South Wales

Unfortunately, the orchard at Atherton was badly damaged during cyclone Larry in 2006, and the trees are currently recovering. Consequently we were unable to make measurements at this site.

At Yeppoon, the hedge treatment was removed due to part of the orchard being resumed for a road development. The trees were replanted, but were still showing signs of relocation stress at the time of the trials.

A description of the training systems and sites is presented in Table 1.

TABLE 1.
Orchard location and the training systems used at each orchard

Region	Site	Vase	Hedge	V-Trellis
Central Qld	Yeppoon	✓	*	✓
Northern Qld	Atherton	**	**	**
Northern NSW	Alstonville	✓	✓	✓

* Some land resumed for road development, trees transplanted but not ready for trials.
** Trees badly damaged during cyclone Larry, currently recovering but not suitable for measurements.

Measurements

Light
Light was measured with a LiCor quantum light meter at the top of the canopy and at the ground level underneath each tree. Light interception percentage was calculated by 100*(1-(floor light measurement/canopy light measurement)). Additionally, at Alstonville, light transmission measurements were taken in two cross-sectional transects on the V-trellis systems.

Tree growth and size
Four to six trees were measured on each system at each orchard. Tree dimensions were measured and volumes were calculated as follows:

- hedge and v-trellis trees - basic cuboid formula (length * width * height),
- vase trees - oblate hemispheroid formula ($4/3\pi\ a^2\ b/2$)

Trunk diameter (girth) was measured 30 cm above the ground, and shoot length was measured on six shoots per tree (see Table 2).

Leaf area and specific leaf weights
Ten leaves per tree were taken from four trees on each tree training system from each orchard. Leaf surface area was measured, then leaves were dried for 24-48 hours at 60°C and weighed upon removal from the oven. Leaf specific weights (g dry weight/cm^2) were calculated for each leaf, and the average leaf specific weight was calculated for each training system.

Leaf nutrients
Leaves were also sampled for nutrients by Incitec Pivot Limited. This analysis quantified levels of Nitrogen, Nitrate, Sulfur, Phosphorus, Potassium, Calcium, Magnesium, Sodium, Chloride, Copper, Zinc, Manganese, Iron and Boron.

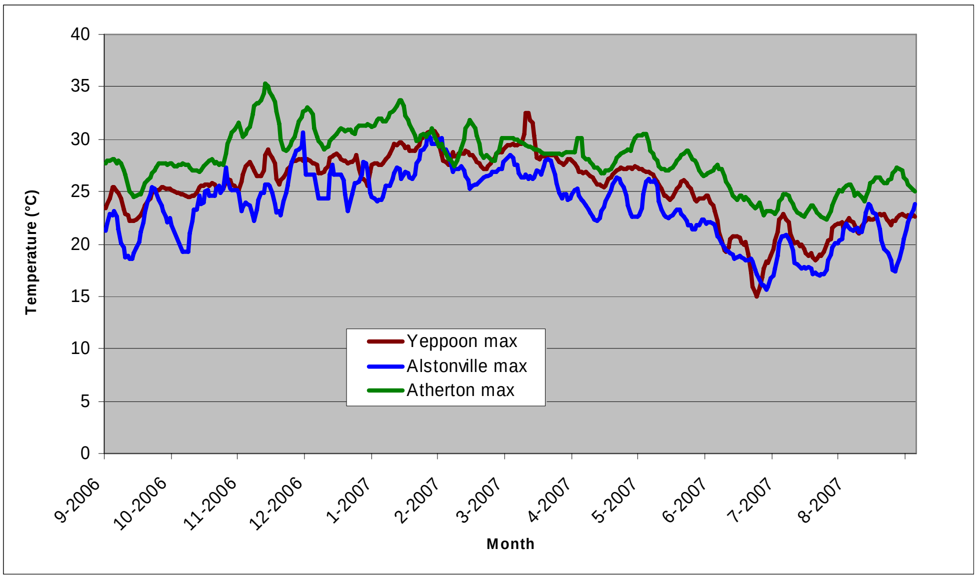
Fruit set and number
Fruit number was recorded on six trees per training system.

RESULTS

Climatic variation

The maximum daily temperature at Yeppoon is, on average, 3.1 °C higher than at Alstonville (Figure 1), while the minimum daily temperature is on average 1.8 °C higher at Yeppoon (Figure 1). Atherton had the highest mean maximum temperatures but Yeppoon had the highest mean minimum temperatures. Yeppoon received relatively low rainfall during the fruit development period compared with Alstonville and Atherton (Figure 2).

(a)



(b)

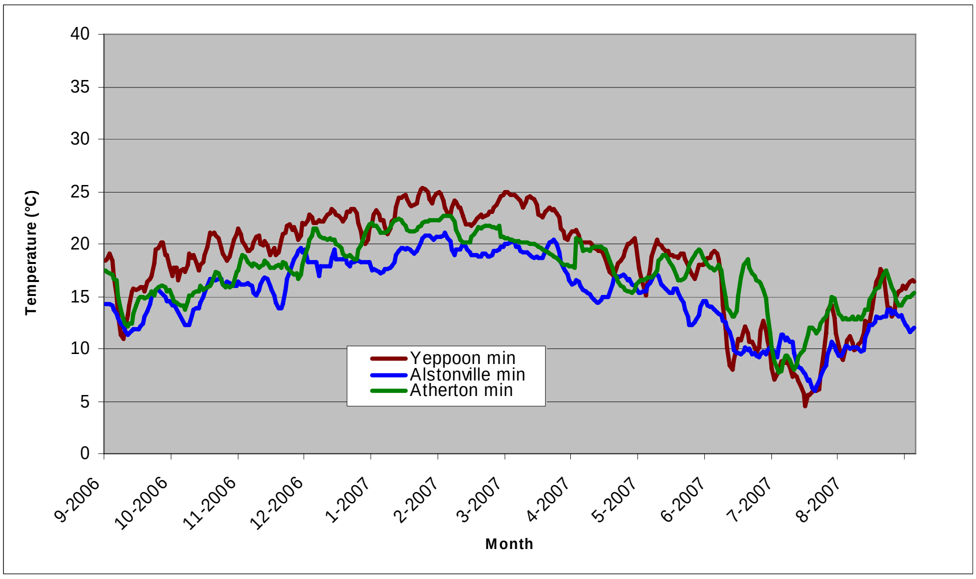
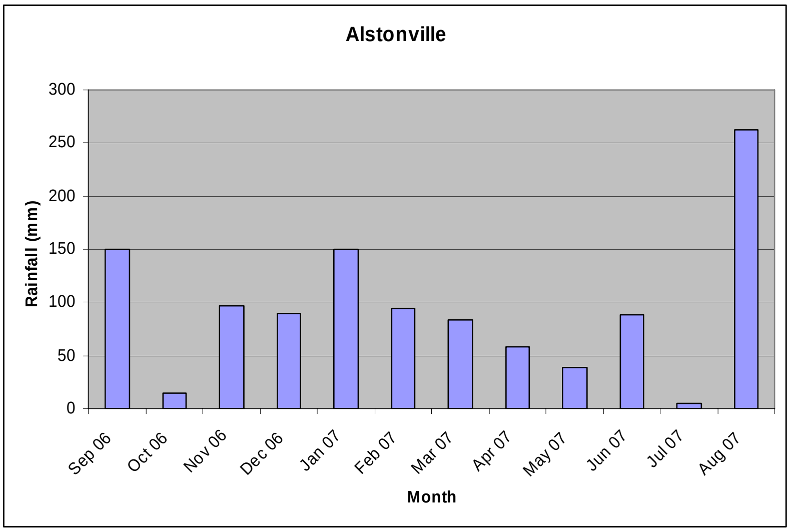


Figure 1. Seven-day moving average of mean (a) maximum and (b) minimum temperatures at Atherton, Yeppoon and Alstonville from September 2006 to August 2007.

(a)



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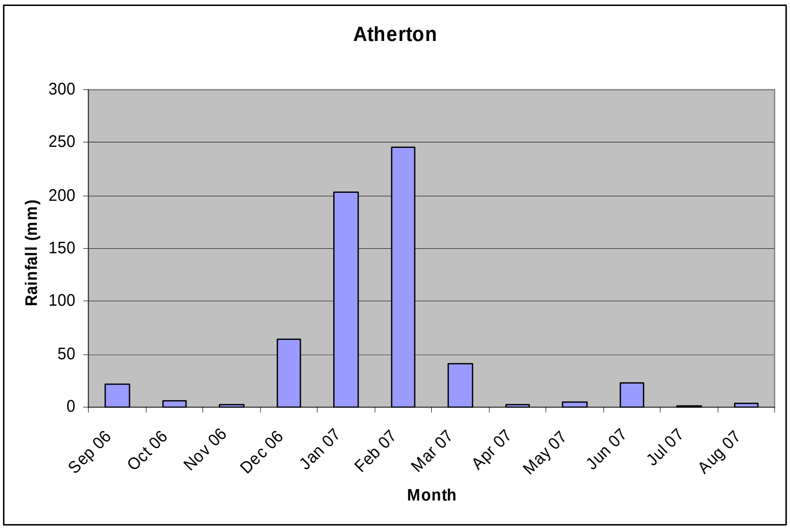

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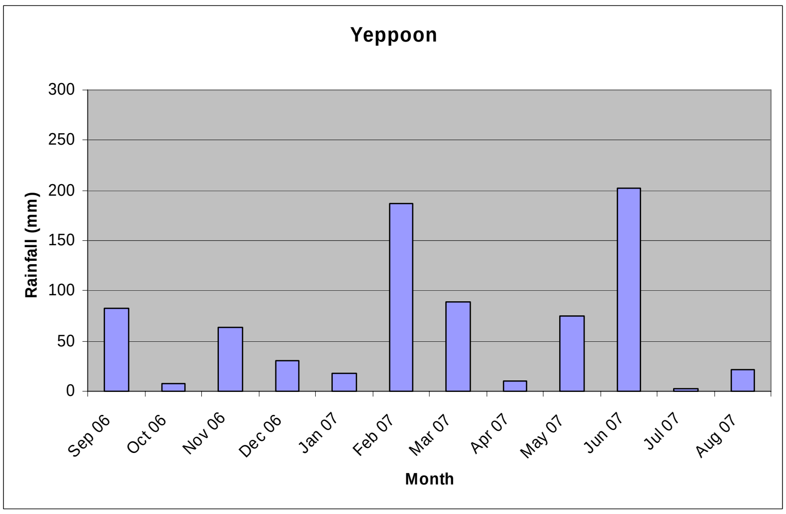

Figure 2. Total monthly rainfall at (a) Alstonville, (b) Atherton and (c) Yeppoon from September 2006 – August 2007

Tree size and growth

Trees at the Alstonville orchard were larger and more vigorous than at Yeppoon. At Alstonville, spreads, heights and tree volumes, were 9%, 15% and 35% greater respectively than at Yeppoon. However, shoot extension growth was only 6% greater at Alstonville (Table 2). Despite being more tropical, lower tree vigour at Yeppoon was probably due to limited irrigation water supply and restricted irrigation which placed young trees under stress. In contrast, tree at Alstonville are growing on deep, highly fertile kraznozem soils.

TABLE 2. *Tree dimensions and vegetative measurements (averages of 6 trees).*

Site	Training system	Average height (m)	Average spread (m)	Average girth (cm)	Average tree volume (m^3)	Average shoot length (cm)
Yeppoon	Vase	2.0	2.7	20.9	8.2	106.0
	V-Trellis	2.0	2.3	10.5	9.2	54.3
Alstonville	Vase	2.4	3.0	25.0	11.3	91.0 *
	Hedge	2.2	2.5	23.5	13.6	87.1
	V-Trellis	2.5	2.8	21.0	15.5	77.6

* Tipped in January

At Yeppoon, shoot extension growth and girth of vase-trained trees was about double that on the V-trellis trees, whereas at Alstonville, vase trees had about 15% longer shoots and greater trunk girths compared with V-trellis trees.

Phenology

Flowering at Yeppoon was two weeks earlier than Alstonville, but peaked 10 days later (Table 3). This is probably a result of temperature differences and water stress effects between the two regions.

TABLE 3. *Phenology and pruning data.*

Site	Training system	Date of budbreak	Date of first flowering	Date of peak flowering	Date of last flowering	Date of Summer Pruning
Yeppoon	Vase	15-Oct-06	1-Dec-06	25-Jan-07	28-Feb-07	15-Sep-06
	V-Trellis	15-Oct-06	1-Dec-06	25-Jan-07	28-Feb-07	15-Dec-06
Alstonville	Vase	15-Oct-06	15-Dec-06	15-Jan-07	25-Feb-07	1-Oct-06
	Hedge	15-Oct-06	15-Dec-06	15-Jan-07	25-Feb-07	1-Oct-06
	V-Trellis	15-Oct-06	15-Dec-06	15-Jan-07	25-Feb-07	1-Oct-06

Light interception

Light interception was similar between Vase and V-Trellis systems (59 and 63% respectively) at the Yeppoon orchard but at Alstonville the V trellis system intercepted 37% less light (Table 4). Compared with the other systems, the hedge system at Alstonville intercepted the largest percentage of light (87% of full sunlight).

Table 4. *Percentage of light intercepted as compared with full sunlight for each training system.*

Site	Training system	Average (%)	Standard Error (%)	Deviation from ideal (60%)
Yeppoon	Vase	62.9	6.55	2.9
	Hedge	-	-	-
	V-Trellis	59.6	5.70	-0.4
Alstonville	Vase	80.1	2.09	20.1
	Hedge	87.2	6.61	27.2
	V-Trellis	50.6	7.98	-9.4

Specific leaf weights

Despite the large variations in light interception at Alstonville, specific leaf weights remained very similar between the three training systems (Table 5). Furthermore, the specific weights of leaves sampled from Yeppoon were about 1.7 times higher than at Alstonville, presumably due to water stress effects.

Due to the variable nature of the light interception levels, the uniformity of the specific leaf weights within each region, and the fact that leaves were thicker in the orchard with ideal light interception, it is possible there are region specific variables, such as climatic conditions, affecting leaf morphology.

TABLE 5. *Means and standards errors of leaf specific weights on each training system*

Site	Training system	Specific leaf weight (g/cm^2)	Standard error (g/cm^2)
Yeppoon	Vase	0.013	0.0006
	Hedge	-	-
	V-Trellis	0.013	0.0007
Alstonville	Vase	0.008	0.0001
	Hedge	0.008	0.0001
	V-Trellis	0.007	0.0002

Vase and V-Trellis trees produced similar numbers of fruit within each orchard (Table 6). While being closer to the ideal light interception range of 60%, the Yeppoon orchard set 10 times fewer fruit than the Alstonville orchard. The large difference in fruit count is probably because the trees at Yeppoon being water stressed.

TABLE 6. *Number of fruit per tree*

Site	Training system	Tree density (number of trees per hectare)	Fruit per tree	Estimated total fruit number per hectare
Yeppoon	Vase	400	8.0	3 200
	Hedge		-	
	V-Trellis	800	9.2	7 360
Alstonville	Vase	400	86.5	34 600
	Hedge	600	26.0	15 600
	V-Trellis	800	75.5	60 400

Yield data

Due to tree age and lack of fruit set, yield data for Alstonville only is presented (Table 7).

At Alstonville, although the vase trained trees produced more trays per tree, due to the higher tree densities of the Maroochy V trellis system, overall yield per hectare was about 14% higher for the Maroochy V system. It is expected that the yield performance of the Maroochy V trellis system will be accentuated with increasing tree age.

TABLE 7. *Yields on 3-year-old KJ Pinks trees on three training systems at Alstonville in 2007*

Training system	Trays per tree	Yield per tree (kg)	Estimated yield per hectare (tonnes)	Trays per hectare
Vase	3.3	21.5	8.58	1320
Hedgerow	2.1	13.9	7.70	1168
Maroochy V trellis	1.8	12.6	10.51	1499

Harvest period

Slightly more early maturing fruit was harvested per tree on the Maroochy V trellis than the other two systems (Hedgerow and Vase) (Figure 3). However, because of higher plant densities per hectare, yield on the V-trellis system should be considerably higher.

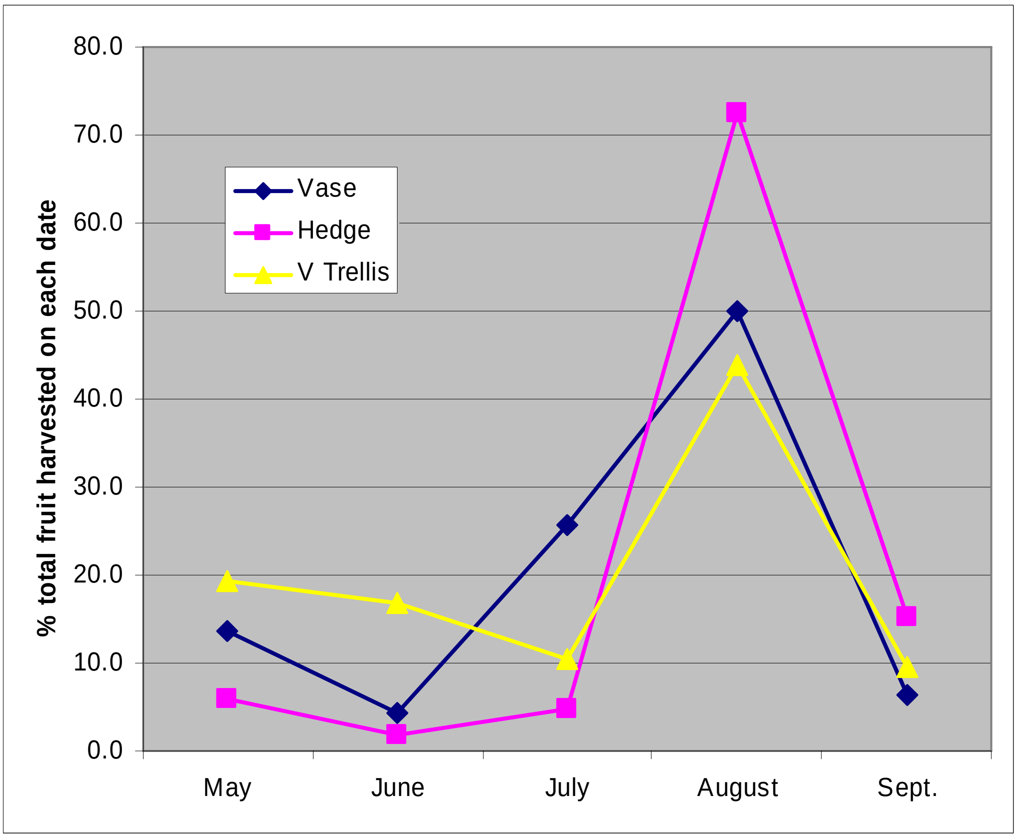

Figure 3. Effects of training system on harvest period of 3-year-old cv. KJ Pinks at Alstonville in 2007.

MECHANICAL PRUNING OF HEDGEROW ORCHARD – OBSERVATIONAL TRIALS GLASSHOUSE MTS 2005-2007

Kerry & Ros Smerdon[1], Roger Broadley[2], Alan George[2], Robert Nissen[2], Sam Price[2], Simon Redpath[2], and Trevor Olsen[3]

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Introduction

Mechanically pruning is currently used extensively in mango, citrus, lychee and avocado orchards throughout Queensland to manage tree size and cropping. It is estimated that about 15% of custard apple orchards in south Queensland (Sunshine Coast, Bundaberg and Yeppoon) use mechanical pruning. It is not commonly used in New South Wales. Mechanical pruning may be best suited to the higher yielding varieties of custard apple such as African Pride and KJ Pinks.

Materials and methods

Observational trials have been established at Glasshouse Mountains on a commercial orchard to evaluate the timing and severity of mechanical pruning in high density hedgerow systems. Observations on the use of growth retardants in conjunction with mechanical pruning are also being conducted.

Growth retardant

To slow vegetative growth and increase fruit size and set, 3.3 litres of 2% Sunny (uniconazole) was applied to each tree in one row of 15 uniform trees when shoot growth was about 30cm. Fruit were harvested from the trees when mature and fruit weight and size measured. Gross returns per hectare were subsequently calculated from actual prices, and using actual fruit quality grades.

Type and timing of mechanical pruning

Trees can be mechanically pruned in two ways:

- The most common way is to flat top the trees, reducing the height of the trees by about 1 to 1.5 metres (inverted cone). This system is preferred for low-moderate vigour trees.
- Alternatively the trees are hedged both on the sides and the top, with side cuts sloping towards the top. This produces a flat top 'Christmas tree', and is better suited to more vigorous trees.

In this study, ten trees were pruned and ten trees were not pruned.

The pruned trees were mechanically pruned to the flat top ‘Christmas tree’ shape on the 26th August 2006, and followed up with a tidy-up hand prune on internal structure on 6th September 2006. For the same ten trees, a second additional summer mechanical prune was carried out on the 17th January 2007. A separate row of 15 trees was also pruned earlier than the others, on the 22nd July 2006.

Results

Growth retardant

Mean weight of fruit from Sunny-treated and untreated trees are shown in Figure 1. Sunny treated trees produced larger fruit, and fewer bulk grade fruit (fruit less than 300 grams). Gross dollar returns per hectare are given in Figure 2.

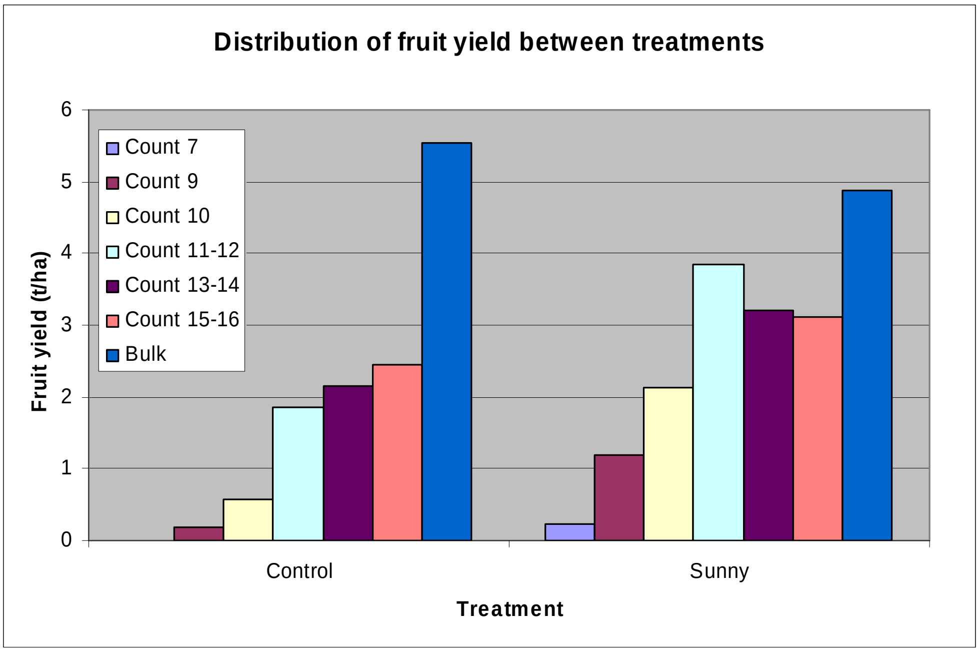

Figure 1. Distribution of fruit yield in Sunny and Control trees. Note one pick on 19th April for both Sunny and Control treatments is missing, thus affecting total yield per hectare.

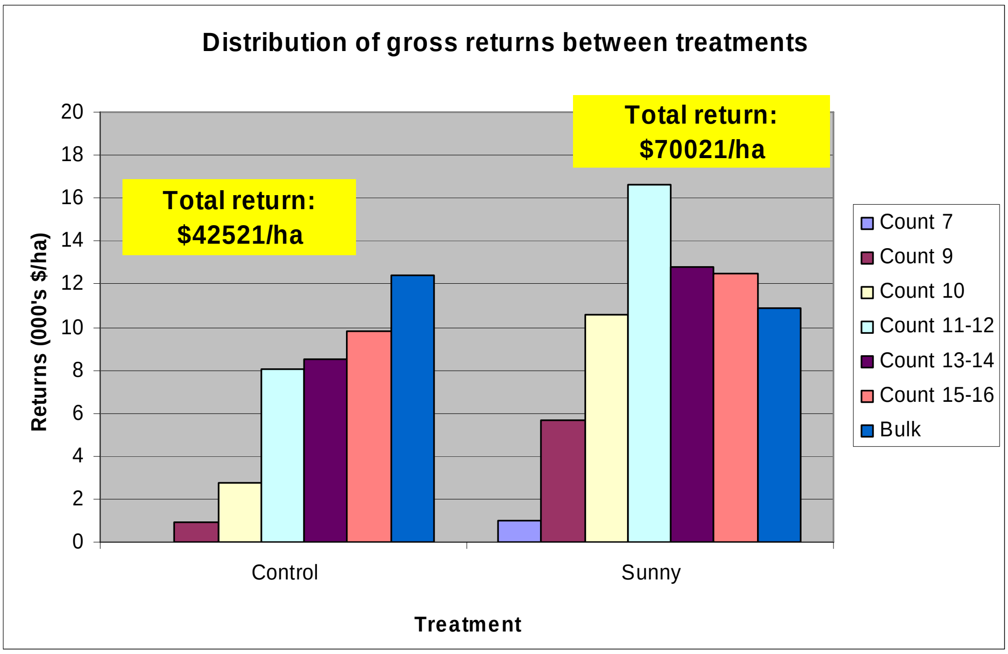

Figure 2. Distribution of gross dollar returns per hectare for the Sunny and Control treatments. Note one pick on 19th April for both Sunny and Control treatments is missing, thus affecting calculated gross return per hectare.

A gross benefit (excluding one pick on the 19th April) of about $28 000 per hectare accrued from the Sunny treatment, giving a 1:5 cost:benefit ratio. Sunny costs about $1 250 per five litres.

Pruning treatments

A comparison between the summer pruned (January) row and the unpruned row showed that the unpruned row produced more smaller (bulk) fruit (Figure 3), and slightly higher gross dollar return per hectare (Figure 4).

Average number of fruit per tree was about the same for pruned and unpruned trees (about 115 fruit) after thinning had occurred. Trees that were pruned in July had approximately 100 fruit per tree, but these fruit were larger. This is attributed to earlier growth resulting from earlier pruning.

Winter pruned (July) trees had larger fruit, but slightly less fruit per tree on any date.

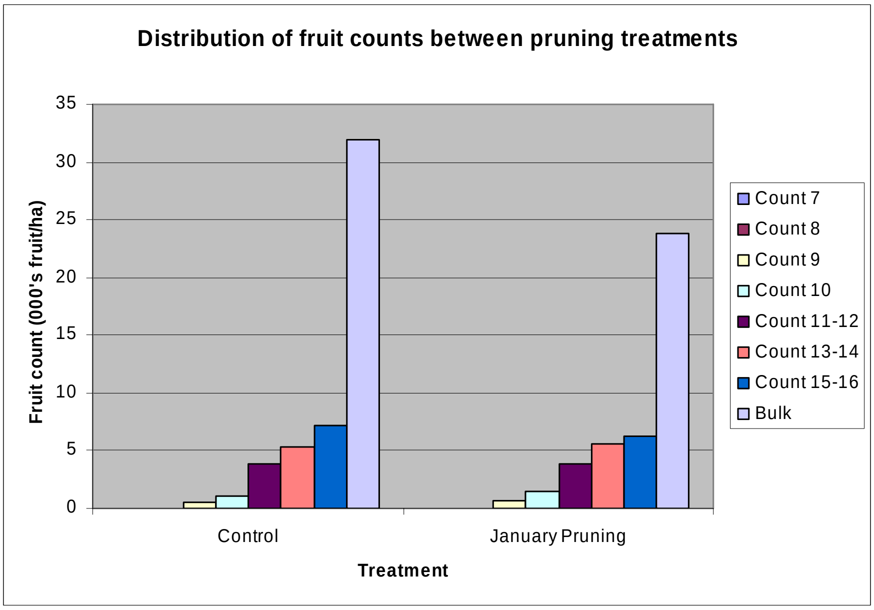

Figure 3. Fruit yield in summer pruned and no summer pruning treatments.

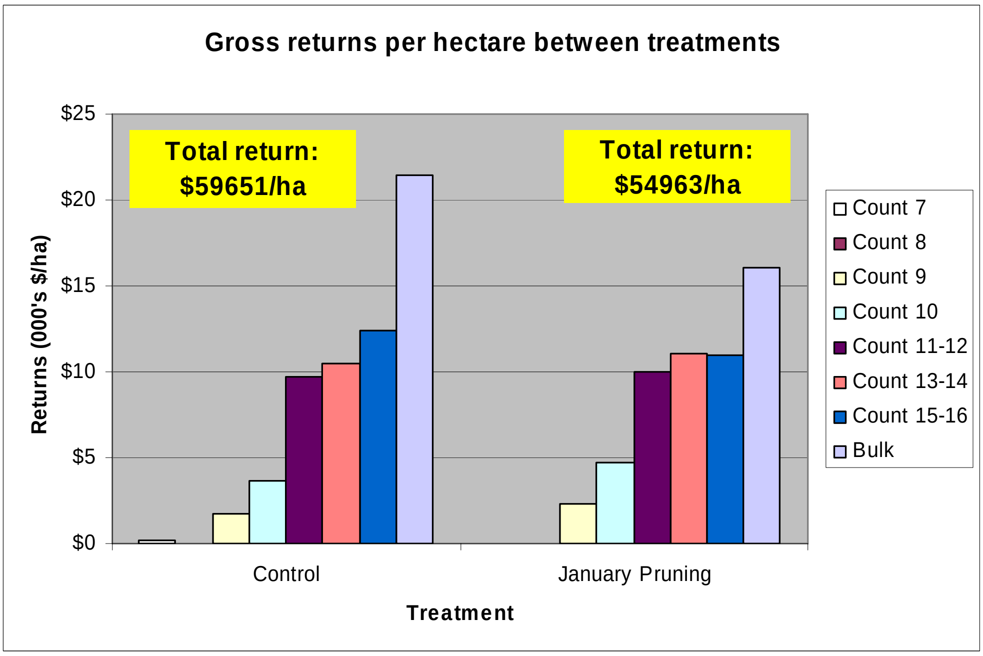

Figure 4. Gross dollar returns per hectare for summer pruned and non-summer pruned treatments.

Discussion

Time of Pruning

Most custard apple trees are currently being mechanically pruned during the late winter when there is no active growth (July to September, depending on district).

In this study, trees which were mechanically pruned in both September and January (mid summer) had fruit which were similar in size from unpruned trees in late February. Fruit numbers per tree in the pruned and unpruned treatments were also similar (111 and 115 per tree respectively).

Pruning results suggest that trees receiving an additional mechanical pruning in January produced a lower gross return per hectare than trees which were not pruned. However this result does not take into consideration the effects of pruning on tree size, in that smaller trees are easier to manage and fruit picking will be easier in the longer term. If ladders (regardless of size) or platforms are used, picking costs increase considerably.

Pruning on 22-29th July produced earlier tree growth than September pruning, and consequently fruit were larger by late February. Slightly lower numbers of fruit per tree were observed in the trees pruned in July (about 100 fruit per tree).

Further studies are being conducted to evaluate timing of mechanical pruning.

Growth retardant - Sunny

The growth retardant uniconazole (Sunny) is used in other crops to increase fruit size e.g. in avocado. In the work reported here, uniconazole had a significant effect on fruit size in the 2006-7 season, and appears to have significant economic benefits. It appears that there is a benefit of about $28 000 per hectare for a cost of about $6 200 per hectare for the 2% Sunny. Note that one major pick on 19th April for both Sunny and No Sunny treatments is missing, and the net effect may be well above the $28 000 net benefit calculated.

Previous studies on the variety Maroochy Gold also showed a combination of rest breaking chemicals (Waiken) and Sunny nearly doubled yield and fruit size (George et al., 2005). Sunny is not yet registered for use in custard apple, and should not be used until registration occurs.

Orchard suitability for mechanical pruning

Not all orchards are suitable for mechanical pruning. Trees need to be structurally pruned from a young age to develop a good framework. Old, large or neglected trees are not well suited to mechanical pruning because a good overall tree structure is not present. In this situation, mechanical pruning will most likely produce excessive vertical regrowth and cross-overs, requiring additional hand pruning. Fruit production will probably cease for 2-3 years. Also, highly vigorous trees are not suited to mechanical pruning.

Pruning costs

Pruning of custard apples are labour intensive. It takes about 30-45 minutes to prune a large mature tree (6 metre diameter). Based on a tree density of 300 trees per hectare and a labour rate of $15.61 per hour, the cost to prune one hectare of trees is about $2 750. If trees are both dormant and summer pruned, the annual cost could be as much as $4 000-$5 000. In contrast, mechanical pruning costs are roughly $180 per hour, and total costs per hectare depend on amount of pruning required. Costs of transporting the pruning equipment to the orchard must be added to this figure. Mechanical pruning to control tree height and size should also result in a significant reduction in harvesting costs.

Tree vigour

Tree vigour will greatly affect the response to mechanical pruning. Ideally, mechanically pruned trees should be of low to moderate vigour. With highly vigorous trees, the main disadvantage is the potential excessive regrowth of strongly pruned upright shoots. If trees are mechanically pruned each year, tree height can be kept down to about 3 metres. This will allow better light penetration, reduce labour costs associated with picking, improve spray penetration and reduce spray costs. Mechanical pruning greatly reduces the time needed to hand prune.

Follow-up hand pruning

Regular mechanical pruning leads to the production of many ‘staghorns’ or branch clusters at the top of the tree. These staghorns produce multiple shoots, which if allowed to regrow, greatly reduces light penetration into the canopy and fruitfulness. Staghorns need to be removed, possibly by follow-up hand pruning or by mechanical pruning every 3-4 years. Besides pruning out staghorns, mechanically pruned trees will also need to be hand-pruned to remove:

- any cross-over limbs
- vigorous vertical water shoots growing up through the centre of the trees, and
- dead or diseased wood

To improve fruit set, this additional pruning should also aim to allow light corridors into the centre of the tree.

The future of mechanical pruning

There is a variety of opinions on whether mechanical pruning is the way of the future. However, with increasing labour costs and the unavailability of skilled labour, mechanical pruning may be the only option.

Mechanical pruning could be used in conjunction with rest-breaking chemicals and chemical growth retardants to further reduce tree size and excessive vegetative growth.

We are also evaluating growth controlling rootstocks and trellising systems which may be practical to use in conjunction with mechanical pruning.

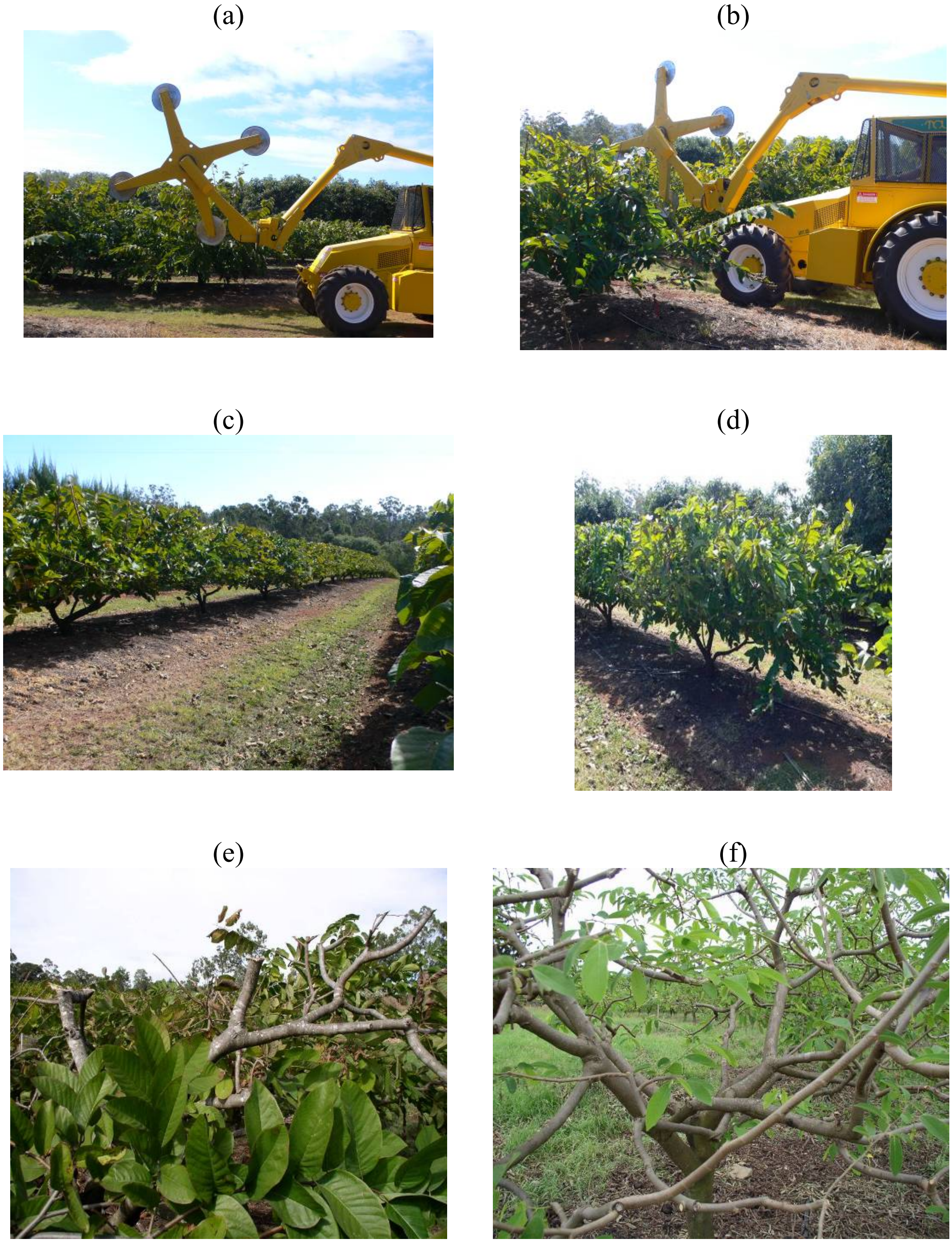

Figure 5. Mechanical pruning of KJ Pinks custard apples at Smerdon's orchard, Glasshouse mountains. (a) circular pruning (b) saw in action (c) and (d) pruned trees (e) staghorns on vigorous shoots (f) follow-up hand pruning to remove staghorns

DEVELOPMENT OF THE MAROOCHY V-TRELLIS SYSTEM – MAROOCHY RESEARCH STATION 2003-2007

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Introduction

A walk through V-trellis system has been designed to compare productivity of trees on this system with conventional vase training system and with a palmette training system. Three evaluation sites have been set up on commercial farms, and also at the Maroochy Research Station. The angle of each trellis arm is 30 degrees from the vertical, there are two planting rows and plant spacing is 1.5 metres on an offset planting system between rows. Walk through access for pruning, picking and other management activities is possible down the centre of the row. Tree sub-leaders are trained to a horizontal espalier system.

Materials and methods

Maroochy V-trellis design

The Maroochy V-trellis system has trees planted at 5 x 1.5 metre spacing, which equals approximately 1 333 trees per hectare. Trees are offset down each row, and the trellising design allows access between the trellis arms for pruning, picking, etc. Wires allow training of custard apple trees into a horizontal espalier system, and the trees are at an angle of 30 degrees to the vertical. Both types of training are designed to reduce tree vigour.

To date all Maroochy V-trellis systems have been planted with cherimoya rootstocks, which are quite vigorous. Only varieties whose fruit set is insensitive to vigour, e.g. KJPinks, are suitable for use on this tree training system (see Plates 1 and 2).

Growth regulator observations

Two small observational trials were conducted in 2005-2006 to evaluate the effects of rest-breaking chemical Waiken and the growth retardants Regalis and Sunny on cv. Maroochy Gold trained on to the Maroochy V trellis system. Treatments were applied to eight four-year-old trees.

Waiken

Chemical manipulation to terminate dormancy and improve flowering of low-chill temperate and semi-deciduous subtropical fruits is possible. A new chemical, Waiken, which is part of a new group of rest-breaking chemicals, was trialled. Broadley et al. (2005) have previously reported on the effects of this chemical on a range of temperate fruits including custard apple. Waiken is a mixture of various fatty acid esters. Its mechanism on breaking dormancy is not known but may expedite changes in endogenous fatty acids which occur during late dormancy (Wang and Faust, 1998).

In this observation, Waiken was applied at the rate of 4% (40mL/L) + potassium nitrate 5% (50g/L).

Growth retardants
Two new growth retardants have been developed in recent years. Uniconazole (Sunny) has been evaluated with a range of tree crops including avocado (Whiley, pers comm., 1999), apple (Zimmerman and Steffens, 1995) and plum (Lurie *et al*., 1997). This product has shown some potential in increasing fruit size of medium-chill plum cultivars in Israel (Lurie *et al*., 1997). It has been reported to have a stronger growth retarding effect on peach plants than paclobutrazol (Avidan and Erez, 1995).

Prohexadione-Ca (BASF Regalis) has been evaluated with a range of temperate fruits (Erez, 2003) and has been shown to be effective as a foliar spray in controlling vegetative growth of peach in Israel. It has been reported to have a stronger growth retarding effect on peach plants than paclobutrazol (Erez, pers. comm). Prohexadione-Ca is primarily transported acropetally via the xylem. Its mode of action is to inhibit the late steps of GA biosynthesis. Compared with paclobutrazol, the active ingredient decomposes very rapidly in the soil and the biological half-life is about 10-14 days. This characteristic would be highly advantageous to commercial growers as it would give a wider range of choices to control vegetative growth.

Treatments: Sunny 40mL/L; Regalis 0.4g/L were applied as foliar sprays at the rate of 3-4 litres per tree in early summer when shoot extension growth had reached 20cm.

Results

At Maroochy Research Station, several varieties have been grafted onto cherimoya rootstock for trial purposes. The system has an initial high set-up cost, but its major limitation is that lower vigour rootstocks need to be tested. Cherimoya produces vigorous plants, and hence low fruit set. High natural fruit set varieties such as KJPinks and Maroochy Star are therefore more suited to the Maroochy V-trellis system, but even these are affected by high vigour rootstocks.

Waiken

Application of the rest-breaking chemical nearly doubled the number of new laterals, which broke dormancy and increased flowering by 20% compared with control trees (Table 1). Despite over 1 000 flowers being produced per tree, fruit set of the Maroochy Gold variety on the V trellis was virtually nil.

TABLE 1. *Effects of the rest-breaking chemical Waiken on bud break and flowering of the custard apple cv. Maroochy Gold at Maroochy Research Station*

Treat	Sub-leader no	No of 1 year old shoots	Total no of 1 year old laterals per tree	No of new lateral per 1 year-old shoots	New lateral length	No of nodes per 1 year-old shoot	% budbreak	No of flowers on new laterals per 1 year-old shoot	Av. no of flowers per new lateral	No of flowers per tree
Control	8.0	23.0	184.0	4.2	14.6	14.4	40.5	6.8	1.4	1151.8
Waiken	8.0	26.0	208.0	8.5	8.7	14.0	61.5	6.5	0.8	1352.0

Figure 6. Effects of rest-breaking chemical Waiken increasing bud break and number of new season laterals.

Growth retardants

Both Sunny and Regalis had a moderate effect on reducing shoot extension growth compared with controls (Figure 7). Sunny was more effective, giving about 17% reduction as compared to 11% reduction with Regalis.

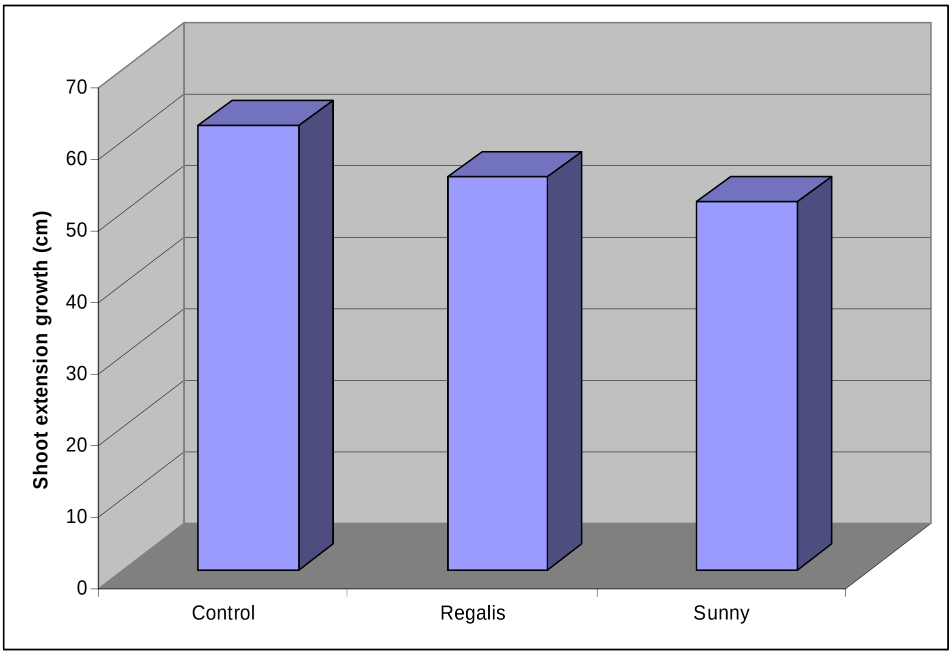

Figure 7. Effects of growth retardants Sunny and Regalis on shoot extension growth of 4-year-old trees cv. Maroochy Gold at Maroochy Research Station in 2005.

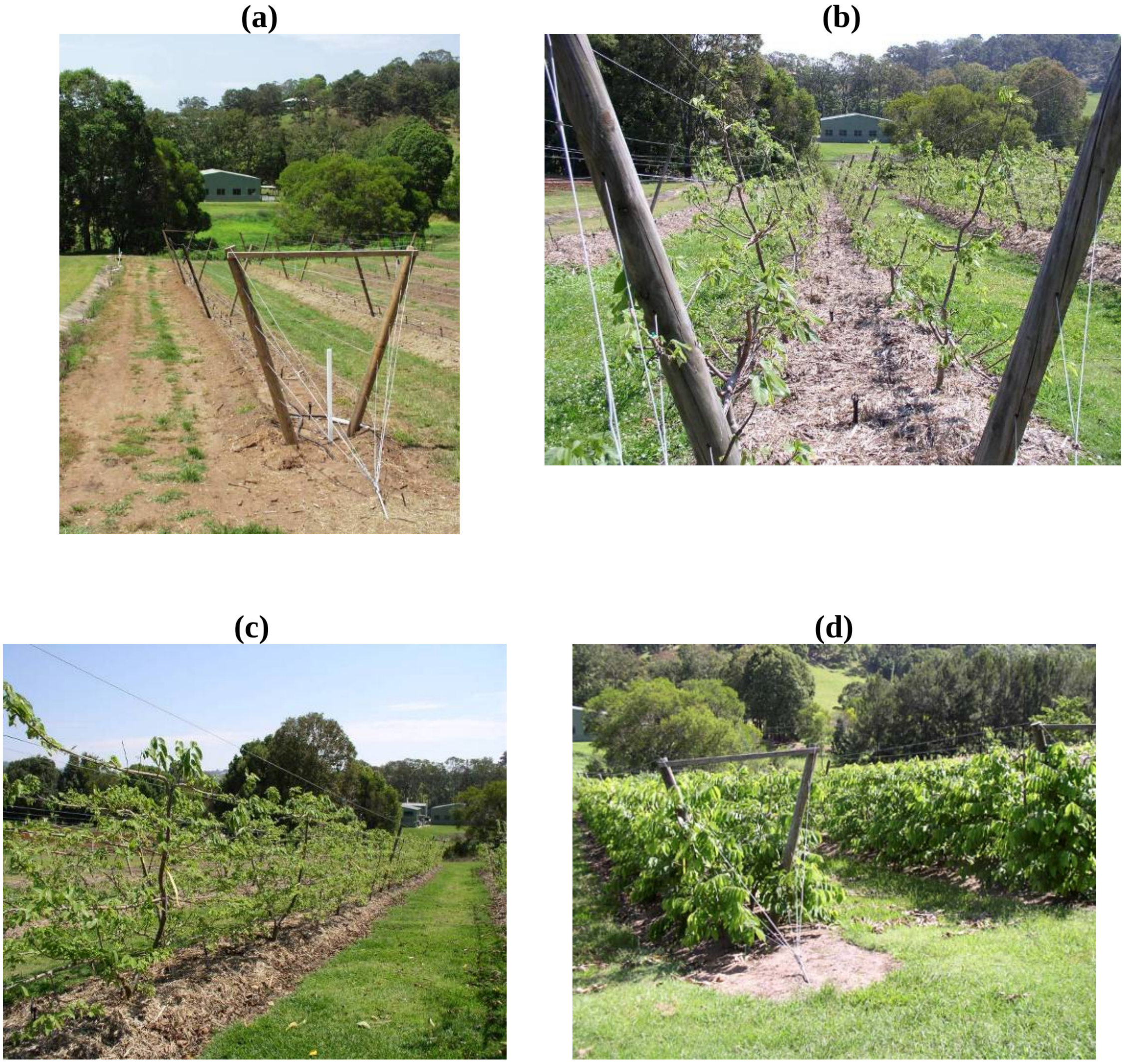

Figure 8. Maroochy V trellis established at Maroochy Research Station. (a) trellis design – note 30° to vertical (b) young trees of Maroochy Star trained on trellis (c) new season's growth (d) excessive vegetative growth and poor fruit set

TECHNOLOGY TRANSFER

A mechanical pruning field day was held at Beerwah on the Sunshine Coast as part of the Fourth Australian Custard Apple and Persimmon Conference in July 2007. Demonstration of mechanical pruning using the spinning saws blades on a rotating arm was carried out and grower discussion groups, discussed the pros and cons of mechanical pruning, hand pruning, crop losses and cost benefits of carrying out such operations.

Mechanical pruning on several farms was examined in the Bundaberg district and a field day held in 2006. Cyclical bar pruning equipment as opposed to the spinning saws blades on a rotating arm was demonstrated on a farmer’s property. Farmer discussions held the pros and cons of mechanical pruning, hand pruning, crop losses and cost benefits of carrying out such operations.

Several articles on tree training and tree pruning have been published in the Custard Apple Newsletter.

RECOMMENDATIONS – SCIENTIFIC AND INDUSTRY

- Research into the development of new training systems for custard apple needs to continue as initial results on the Maroochy V-trellis and hedgerow systems are very promising. Currently only one variety, KJ Pinks, is suitable for the new systems. However, we propose to test a wider range of high fruit setting varieties.

- Control of tree vigour on the new training systems using dwarfing and semi-dwarfing rootstocks needs further investigation. A range of potential dwarfing rootstocks including Taiwanese sugar apple, African Pride seedlings of intermediate vigour and *Rollinia* spp. are currently under investigation.

- Further studies are needed on the use of rest breaking chemicals and growth retardants to increase performance of new training systems.

- Further studies are needed to clarify the timing and severity of mechanical pruning and to determine the effects of mechanical pruning on newly established orchards.

- Further research is needed to more fully evaluate the effects of exclusion netting on orchard micro-climate and its effects on fruit set, yield and fruit quality.

- We recommend that commercial farmers trial these new systems, initially on a limited scale until they can be fully evaluated.

ACKNOWLEDGMENTS

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