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Floral Manipulation and Canopy Management in Longan and Rambutan.

A report for the Rural Industries Research and Development Corporation

by Yan Diczbalis and Dr. James Drinnan

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Researcher Contact Details

Mr Yan Diczbalis
Senior Research Scientist
Horticulture and Forestry Science
Department of Primary Industries and Fisheries

Phone: 07 40641128
Fax: 07 40642249
Email: yan.diczbalis@dpi.qld.gov.au

Dr James Drinnan
Research scientist
Horticulture and Forestry Science
Department of Primary Industries and Fisheries

Phone: 07 40484647
Fax: 07 40923593
Email: james.drinnan@dpi.qld.gov.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON   ACT   2600
PO Box 4776
KINGSTON   ACT   2604

Phone: 02 6272 4819
Fax: 02 6272 5877
Email: rirdc@rirdc.gov.au.
Website: http://www.rirdc.gov.au

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Foreword

The longan (*Dimocarpus longan*) and rambutan *(Nephelium lappaceum*) are members of the Sapindaceae family. Both crops are native to Asia with longan considered to be subtropical in nature while rambutan tropical in nature. Both crops have been grown commercially in Australia for the last 20 years. Longan production occurs along the east coast of Australia with the majority of commercial longan plantings on the Atherton Tableland region (17°S) at an altitude of approximately 400 meters. Rambutan production is primarily confined to the wet tropical north Queensland coast (17ºS) and the wet/dry tropics in the vicinity of Darwin (12°S).

Rambutan and longan experience irregular flowering, particularly when they are grown outside of their preferred environment. The north Queensland production region for these crops can be problematic due to a lack of consistent pre-flowering cold requirement for longan and pre-flowering dry weather requirement for rambutan. Excellent cropping can be achieved on both crops in some years, however poor flowering or nil flowering in “off” years make management and economic viability difficult for producers.

To further exacerbate the irregular flowering issue, heavy pruning, every three to four years, for tree size control to assist tree management, and protective bird and bat netting control measures, reduce potential yields in the subsequent year. This project examined and reports on a range of pruning and flower regulation options to improve productivity.

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Peter O’Brien
Managing Director
Rural Industries Research and Development Corporation

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Contents

Executive Summary

What the report is about?
The report details the results from a series of experiments conducted on longan and rambutan, two member of the Sapindaceae family, which examine the effects of pruning times and the effects of a range of physical and chemical growth regulators on vegetative growth, flowering and subsequent yield.

Who is the report targeted at?
The report is targeted at members of the relevant industry associations and associated State or Federal Government research and extension personnel.

Background
The longan industry is mostly located along the east coast of Queensland with minor planting's in northern NSW. Current longan plantings are reported to be in the vicinity of 70,000 trees and the annual production of 1000 plus tonnes are valued at $5.0M. Approximately 80% of the industry is located on the Atherton Tablelands Region of far north Queensland.

The rambutan industry is confined to the wet tropical coast of far north Queensland and the rural area around Darwin in the NT. The bulk of the industry (22,000 trees, 75%) is situated in north Queensland with the value of production estimated at $4.3 M.

The variable and unpredictable nature of production in these crops has been a major hindrance in the development of the industries. Assured flowering, and cropping every season, would be of great economic benefit to the industries concerned and the north Queensland rural regions, where longan and rambutan are cultivated. Regular crop production would allow industries to plan their development and marketing strategies. These industries have included flowering management and tree size control as major production issues limiting industry development within their respective strategic plans. Industry planning officers believe that by 2010 the longan and rambutan industries could potentially be valued at $15M and $6M respectively.

Aims/Objectives

- Maximise the production potential of longan and rambutan by improving consistency of flowering along with canopy height management
- Examine the effects of a range of physical and chemical growth regulators on vegetative growth and flowering

Methods used
A series of experiments were undertaken to test the application of various pruning strategies and the effects of physical and chemical growth regulators on vegetative growth, flowering and subsequent fruit set. Field trials were conducted in North Queensland on government research stations and growers' properties over four years. In longan, additional work was carried out to investigate crop thinning recommendations and crop forecasting guidelines. Whereas in rambutan, additional work included the examination of synthetic auxins to manipulate the sex ratio of flowers.

Results/Key findings

- In relation to the objectives of the report

In longans the results indicate similar responses to potassium chlorate ($KClO_3$) across cultivars, soil type and climates. On the first application a rate around 5-10g/m^2 of the canopy spread reasonably evenly under the canopy and watered is suggested. While for foliar application, rates of 0.2% applied until runoff was found to be most effective. On repeat applications the ideal rate varies depending on whether the trees are in a conducive or non-conducive state to flower. In conducive trees (dormant mature vegetative growth, during normal flowering time) rates of 10g/m^2 resulted in maximum flowering while in non conducive trees (active vegetative growth, young flush, out of season flowering) rates of 10-20g/m^2 of the canopy are required and even then the flowering response is sometimes still poor. Similarly for the foliar applications, in conducive trees lower rates (0.5%) were

required then in non-conducive trees (1%). The high rates required to achieve reasonable flowering in the non-conducive trees resulted in excessive leaf fall and therefore cannot be used.

Two factors identified in determining the success of $KClO_3$ application in triggering good flowering on repeat applications were the level of flushing or stage of growth and the leaf nitrogen level in the trees at the time of application. It was found flowering was best when $KClO_3$ was applied to trees which had dormant mature vegetative shoots and the longer the shoots have been mature the better, although some flowering can occur in shoots with active growth it is never as good. When trees are heavily pruned or during the hot wet summer months vegetative growth is strong and flushing tends not to mature and become dormant before flushing again, so achieving good flowering in these conditions is difficult. It can take up to 2 years for growth to stabilise after heavy pruning. Leaf nitrogen levels indicate that above 1.7% good flowering is generally difficult to achieve on repeat applications, while at levels below 1.2% good flowering is more easily achieved.

With increasing use of $KClO_3$ longan trees are being cropped more heavily and consistently than ever before. Heavily bearing longan trees are very prone to overcropping resulting in small poor quality fruit and tree decline. Trials have indicated that trees are capable of supporting around 3-5kg of fruit/m^2 of the canopy surface area. This usually requires that 40-60% of the crop load be removed from trees in full flower.

The ability of $KClO_3$ to trigger out of season flowering allows growers to time the flowering and cropping of their trees. Trials have allowed the development of a predictive formulae using heat sums which has allowed growers to predict the crop harvest date from different application dates so that they can time their crops with market opportunities.

The root pruning and chemical growth retardant work demonstrated that vegetative growth could be reduced with the use of monthly sprays of foliar paclobutrazol (0.5%) either by itself or in combination with root pruning. Neither treatment improved flowering.

In rambutan research into pruning and manipulation of floral induction in rambutan suggest that there is no easy solution to managing pruning and subsequent flowering in the north Queensland growing environment. Unlike the use of $KClO_3$ in longan there is no flowering 'switch' yet discovered for rambutan. This project has improved the understanding of the effects of pruning time on subsequent regrowth and flowering. Unfortunately none of the trialled pruning times significantly improved the chances of obtaining flowering and fruit set in the subsequent season. This leads to the conclusion that growers will need to consider staggering their heavy pruning operations through out the orchard if they wish to ensure some production in every year. The results clearly indicated that nearly two full seasons of growth was required before growing terminals were at a stage that flowering could occur. None of the growth regulating techniques trialled significantly improved flowering yet there were indications that the physical growth regulating techniques (cincturing and root pruning) may warrant further investigation. Growth regulating chemicals other then those trialled should be tested as they become available.

- Additional findings

In rambutan the use of synthetic auxins to manipulate the sex ratio of rambutan flowers did show strong promise. This technology could significantly improve the productivity of early flowering orchards. Further work will be required to confirm the efficacy of the technology as well as to seek product registration.

Implications for relevant stakeholders for:

- Industry

The project has developed a number of strategies and management options that longan and rambutan growers can use to maximise the production potential by improving consistency of flowering along with canopy height management. The strategies differ for each crop and further developments are envisaged as the outcomes of the work are fully incorporated into industry practice.

- Communities

Both longan and rambutan are tropical fruits which require a high labour input during harvesting, packaging and marketing operations. Consistent and increased production leads to more efficient business operations. Ultimately more profitable industries lead to profitable communities *via* increased employment opportunities.

- Policy makers

There are no direct implications to policy makers except the understanding that tropical horticulture industries such as the production of longan and rambutan are important part of horticulture production in northern Australia. Although these industries are small in their own right they contribute to the economic diversity of the horticulture industry and regional employment opportunities.

Recommendations

The recommendations below are targeted specifically at growers of the crops highlighted below:

- Longan

Research work from this project has demonstrated that the chemical Potassium Chlorate ($KClO_3$) is a powerful flowering inducing agent in longan trees (flowering occurring around 6-8 weeks after application). Ideal rates, timings and methods of application have been determined as well as guidelines for crop thinning and crop maturity forecasting. Controlling vegetative growth was unsuccessful using root pruning but foliar sprays with paclobutrazol did reduce vegetative growth.

- Rambutan

Management of pruning still remains an important issue, particularly as there is a need to maintain tree height to a level which allows for economical picking and netting for crop protection purposes. Our studies suggest that trees require 16 months or more following heavy pruning to begin to flower and fruit with 21 to 25 months being necessary for the highest yields to occur. The earlier in the calendar year that pruning can take place the better. However, this may not always be possible because in most cases trees are still bearing fruit with harvest operations generally commencing from mid February. The other alternative is for pruning to occur from August when warming spring temperatures allow the new post pruning flush to develop quickly. Growers need to consider managing pruning so as to avoid heavy pruning of the entire orchard in the same year. Growers may consider splitting their rambutan orchard into four, with heavy pruning carried out on a block of trees every four years. This form of management ensures that half of the orchard is in a state of growth that allows for full flowering and fruit-set to occur.

1. Longan

1.1. Background

The longan industry in Australia is concentrated along the east coast of Queensland and on the Atherton Tablelands (inland from Cairns). The major centres of production are Mareeba, Proserpine, Yeppoon and Bundaberg. The industry uses two main varieties, Kohala (large open vigorous variety with early maturing fruit) and Biew Kiew (a smaller compact tree with late maturing fruit). There are also a number of other varieties grown, including Ponwaii, Chompoo, Homestead, Daw and Haew.

The first commercial longan trees were planted in Queensland around 20 years ago and there was a rapid rise in plantings during the 1990's. Today there are around 70 000 trees or 500 ha planted. Production has reached 1 500 – 2 000 tonnes/year worth around $5 million.

Fruit production of longan in Queensland has been characterised by large variations in production from year to year (from 500 to more than 1500 tonnes/year). The variable and unpredictable nature of the production has been a major hindrance in the development of the industry. Fruit production is susceptible to climatic variation from year to year with flowering being largely controlled by the extent and duration of the winter minimum temperatures. However, other factors such as the stage of growth (flushing), previous cropping, level of nutrition, water supply and level of pruning, are also known to influence the flowering. Tree size control (pruning) is considered an essential operation for efficient orchard management for ease of harvesting, spraying and netting. However, it can further complicate the flowering process with many orchardists experiencing a loss in production for a season or two, following heavy structural pruning.

Assured flowering each year would be of great economic benefit to the longan industry and to the many rural towns where longans are cultivated. Regular cropping would lower the costs of production and would allow the industry to better plan its development and marketing strategies. The extent to which the industry views these problems as critical is born out by the fact that flower management was identified as a major production priority limiting the industry development in their strategic plan. This project was developed in response to this need.

As this project was being developed, researchers in Taiwan discovered that the chemical, potassium chlorate ($KClO_3$) could be used to induce flowering in longan trees. It was observed that longan trees in close proximity to an area where fireworks were regularly used, flowered at sporadic times throughout the year. After extensive investigation, it was determined that the flowering was linked to potassium chlorate ($KClO_3$) which was the main ingredient in the fireworks. This discovery which has brought major changes to the longan industries has rapidly been adopted in longan production areas in South-East Asia and now here in Australia.

The use of $KClO_3$ has brought with it, another set of problems concerned with its most effective/efficient use. For example, the ideal rates, methods and timings of application for the various varieties, management levels, climatic conditions and soil types in Queensland needed to be determined. The Australian pesticides and Veterinary Management Authority (APVMA) have classed $KClO_3$ as a fertiliser with 32%K and as such it does not require a registration to be used on longan.

With the effectiveness of $KClO_3$ in triggering flowering and the likelihood that its use would become a major strategy for successful longan production in Australia, this project was modified to concentrate on the factors responsible for the most effective use of KClO3 to trigger flowering.

Information from overseas research was gathered and research trials established in Australian conditions (varieties, soil types, climates). The interaction with tree size control (pruning) was of particular interest as it is considered an essential part of orchard management. Trial work was conducted on growers' properties and government research stations.

Objectives

- Maximise the production potential of longan in a tropical environment by improving consistency of flowering.
- Determine the most appropriate rates, timings and methods of potassium chlorate (KClO3) application in longan.
- Determine the influence of flush age and leaf nitrogen on the effectiveness of KClO3 in triggering flowering.
- Determine the most appropriate level of crop thinning required to achieve good fruit size.
- Develop a heat sum to be used as a predictive tool for crop maturity based on the application time of KClO3.
- Determine if chemical growth retardants or root pruning can be used to control vegetative growth and improve flowering.

2. General Materials and Methods

The research trials for this project were conducted on mature trees 6-15 years old growing on commercial longan farms and on government research stations. Trial work was carried out in the Mareeba Dimbulah Irrigation Area (17^{o}S,145^{o}E; 400m ASL) on the Atherton Tablelands about 50 km inland from Cairns in north Queensland. Mareeba is the major production area of the Australian Longan Industry. Mareeba has a dry tropical climate with wet summers and very dry winters (Figure 1.1). The temperatures vary from a maximum of 32^{o}C in summer to 26^{o}C in winter to a minimum of 20^{o}C in summer and 11^{o}C in winter with very occasional frosts (Figure 1.1).

The trees for these trials were mostly produced from Marcots although the industry uses grafting to a limited extent as well.

Trees are planted at high densities with 200 – 400 trees/ha (4-8 m x 6-8 m row spacings) and are intensively managed. They are provided with adequate nutrients throughout the year with regular ground and foliar fertilisers used. Nitrogen is usually withdrawn leading up to flowering to help reduce the chance of vegetative flushing and promote reproductive growth. Leaf and soil samples are taken regularly to check for deficiencies. Trees are irrigated regularly (with under-tree sprinklers) throughout the year, except for a few months prior to natural flowering when irrigation may be withheld to help promote vegetative dormancy and reduce the chance of flushing there by aiding flowering.

The sprinklers cover the entire root system. Trees are sprayed with insecticides and fungicides as required. Tree height is controlled using mechanical pruners which hedge the tops at 4 – 7 m above the ground. Sides of the trees are also hedged occasionally and lower branches are skirted. Some manual pruning is also carried out to keep the centre of the trees open. Pruning is considered an essential operation to allow efficient orchard maintenance (harvesting, spraying and netting). Most of the trees are growing on a well drained sandy loam soil of granitic origin which has a low water and nutrient holding capacity.

Under normal seasonal conditions, longans flower during winter (July-August) and the fruit develops through spring and ripens in summer (January to March) the following year. The trees usually flush again following harvest and then flower on this new wood during winter.

The two main varieties grown in Australia are Biew Kiew and Kohala, although there are smaller plantings of other varieties including Chompoo, Daw, Haew, Homestead and Ponwaii.

The research work for this project was developed in conjunction with the industry from their strategic plan and discussion at association meetings, field visits and discussion with other longan researchers.

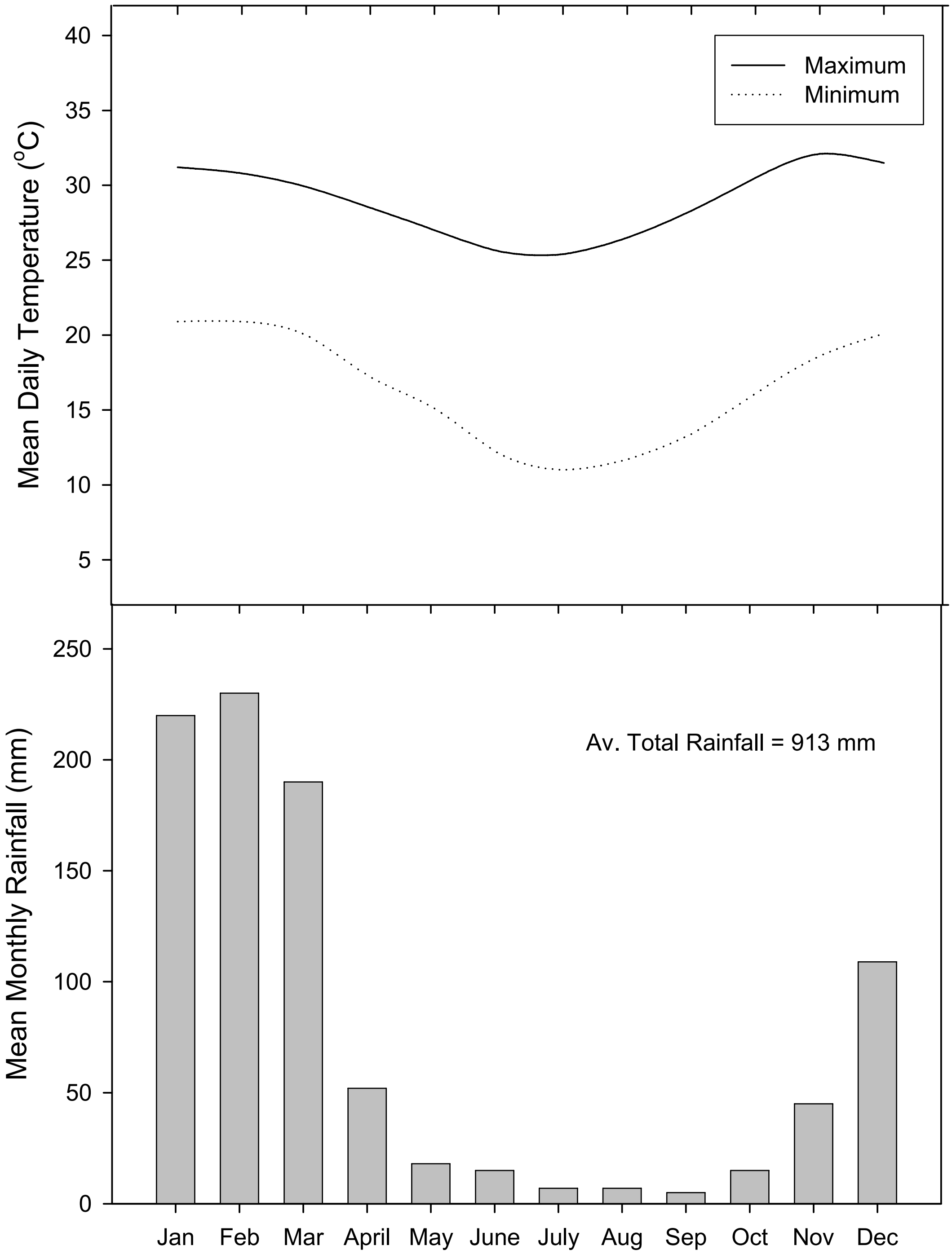

Figure 1.1. a). Mean Maximum and Minimum Temperature and b). Mean monthly rainfall for Mareeba.

The trials conducted were:

1. Methods and rates of $KClO_3$ application on trees not previously treated with $KClO_3$.
2. Methods and rates of $KClO_3$ application on trees previously treated with $KClO_3$.
3. Timing and rates of application – influence of flush age on flowering response.
4. Relationship between leaf N and flowering with $KClO_3$ application.
5. Influence of the timing of application on the harvest date.
6. Controlling vegetative growth with chemical growth retardants and root pruning.
7. Level of fruit thinning required to maintain good fruit quality (bearing capacity).

3. Longan Literature Review

The longan *(Dimocarpus longan)* is a member of the Sapindaceae family. It is considered to be subtropical in nature and can experience irregular flowering, particularly when they are grown outside of their preferred environment (Menzel and McConchie, 1998, Nakasone and Paull, 1998, Winston and O'Farrell, 1995). The production areas in Queensland are considered to be problematic due to a lack of consistent pre-flowering cold requirement. Excellent cropping can be achieved in some years, however, poor flowering or no flowering in other years, make management, marketing and economic viability difficult for producers. To further complicate the irregular flowering issue, heavy pruning for tree size control to assist with tree management operations (harvesting, spraying, netting) reduces potential flowering further.

In longan the level of flowering can often be related to the extent and duration of the winter minimum temperatures, with cool temperatures promoting vegetative dormancy, reducing vegetative flushing and increasing flowering (Menzel *et al*., 1999). However other factors such as the previous cropping level, level of nutrition, water supply, and level of pruning have also been observed to influence the flowering response (Winston and O'Farrell, 1993, Menzel *et al*. 1999).

Recent work published by Menzel *et al*., (1999), reported that for lychee (closely related to longan), floral induction occurred when shoots were a few millimetres long during cool temperatures (<20^{o}C). The researchers then showed that flush development was strongly related to radiation and temperatures. The research conducted on longan showed they behaved in a similar manner to lychee. In lychee, cincturing and root pruning, as well as withholding water and nitrogen, are all reported to help control vegetative growth and promote flowering (O'Hare, 1989, Zang, 1997 and Huang, 2002). These findings suggest that flowering in terminal flowering tropical trees such as longan, is complex and dependant on many interacting factors.

Chemical methods of promoting vegetative dormancy and/or promoting flowering, are reported in various crops. In lychee, a range of chemicals have been reported to have beneficial effects on flowering and include sodium naphthalene acetic acid, daminozide, CCC, ethephon, paclobutrazol and MKP (O'Hare, 1989, Nagao and Paull, 1998). In longan, it was recently discovered that potassium chlorate ($KClO_3$) applied to the soil under the tree can induce flowering (Yen, 2000, Sritontip *et al*., 1999). Various other chlorine based oxidising agents are also reported to be useful (Sritontip *et al*., 2005, Jitaareerat 2002). The mode of action is not currently understood, however, researchers in Thailand believe the $KClO_3$ disrupts nitrogen metabolism in the roots which assists with flower induction. No work has been conducted on the hormonal changes occurring in the plant following $KClO_3$ application. Preliminary work here in Australia (Diczbalis pers. comm.) suggests $KClO_3$ can stimulate synchronous and out of season flowering.

Overseas literature suggests rates of 1 – 16 g $KClO_3/m^2$ of the canopy are effective at stimulating flowering when applied evenly over the surface of the soil under the tree canopy and watered in. Most overseas work has been conducted on local varieties only. Manochai, *et al*., (2005) found that a rate of around 4 – 12 g/m^2 for the variety, Daw, and 1 – 4 g/m^2 for the variety Chompoo, effective on the first application and 10 g/m^2 on the second application. Sritontip *et al*.(1999) found 5 g/m^2 of the canopy, effective at triggering flowering, while Yawoot, (1999) found rates of 4 – 16 g/m^2 worked well in the normal flowering season but 16 g/m^2 was required out of season. Nagao and Ho (2000) found 250 or 500 g/tree (≈ 10 – 20 g/m^2) on 7 year old trees of Bew Kiew, Chompoo, Kohola and E-Wai, was effective. Many researchers have reported that the response to $KClO_3$ is best during the normal flowering period or just following this (co-inciding with the cooler dryer months) and poorest in the middle of the hot wet season.

Although ground application has been the main method of application, many researchers have also studied trunk and stem injection and foliar applications (Nagao and Ho, 2000, Manochai et al., 2005, Sritontip *et al*., 1999, Viriya-Alongkoron *et al*., 1999). Foliar application rates have ranged from 0.1 – 0.2%. These methods have generally been less effective, particularly on the second and subsequent applications, when out of season flowering is trying to be triggered (Yawoot, 1999) or when trees have been heavily pruned and have a lot of young flush. Manochai *et al*. (2005), found flush age had a dramatic effect on the flowering response with good flowering only occurring in shoots mature for 40-45 days. Shoots less mature than this, flowered poorly. Yen, (2000), found flowering was independent of flush age but this was on the first application.

Nagao and Ho, (2000), Yen, (2000) and Manochai *et al*., (2002), found foliar rates of 0.2% effective but only stimulated flowering on treated branches. Sritontip *et al*., (2005) and others, have found high rates (above 0.2%) caused excessive leaf drop.

4. Methods and Rates of Potassium Chlorate Application

4.1 Introduction

Potassium chlorate is known to induce flowering in longan trees. However, its use is relatively new in Australia. Trials were conducted to ascertain the ideal rates and methods of application for locally grown varieties, soil types and climates.

4.2 Material and Methods

Two trials were conducted. In the first trial 15 year old trees growing on the Atherton Tablelands in North Queensland on a granitic sandy soil were used. Trees ranged in size from 4x5 m to 6x6 m. These trees had not previously been treated with $KClO_3$. The treatments consisted of a range of rates and methods of application on the varieties Biew Kiew, Kohala and Ponwaii. The rates used were 2, 5, 10 and 15 g/m^2 (calculated by multiplying the width and breadth of the tree). While the methods used were - evenly broadcast under the canopy (2 m radius from the trunk) with and without leaf litter left under the tree, a spot application spread over just 1 m^2 under the tree canopy, a collar drench around the trunk, broadcast over only half the area under the canopy, trunk and root injections. Trunk and root injections were conducted by dissolving 16g of $KClO_3$ into 100 ml of water and injecting this (using hypodermic syringes) into 5 areas around the trunk or major roots. Trees were treated around 10am when the transpiration rate was high. It took 30-40 minutes for the solution to be taken into the plant. Following all treatments the $KClO_3$ was thoroughly watered in.

Treatments consisted of 2-3 single tree replicates. All treatments were applied during winter (June-July) when natural flowering is expected. Following the treatments the overall level of flowering (% of canopy) and tree health were recorded.

In the second trial 8 year old trees (4x4 m) of the varieties Kohala, Homestead, Biew Kiew and Chompoo were treated with foliar applications of $KClO_3$ until runoff. The rates used were 0.05, 0.1, 0.2, 0.5 and 1.0%. Either the whole canopy, half the canopy or just parts of the canopy were treated. Treatments mostly consisted of 2 tree replicates. Following the treatments the overall level of flowering (% of the canopy) and tree health were recorded.

4.3 Results and Discussions

Results from both trials indicated that each of the varieties behaved in a similar manner. The rate of application trial (figure 3.1) indicated that all the varieties are very sensitive to $KClO_3$ when applied for the first time and during the natural flowering season and flower very well. Flowering was greater, earlier and more uniform in all treatments compared to untreated control trees. Panicles were also usually larger and stronger. The more uniform crop development aids management operations such as spraying, thinning, netting and picking and thereby reduces production costs. Panicles emerged 7-9 weeks from the date of application. Factors such as the previous pruning/cropping levels, leaf nitrogen levels, stage of flush development in the tree, time of year (which are known to influence natural flowering) had little effect on the effectiveness of the $KClO_3$ in triggering flowering on this fruit application.

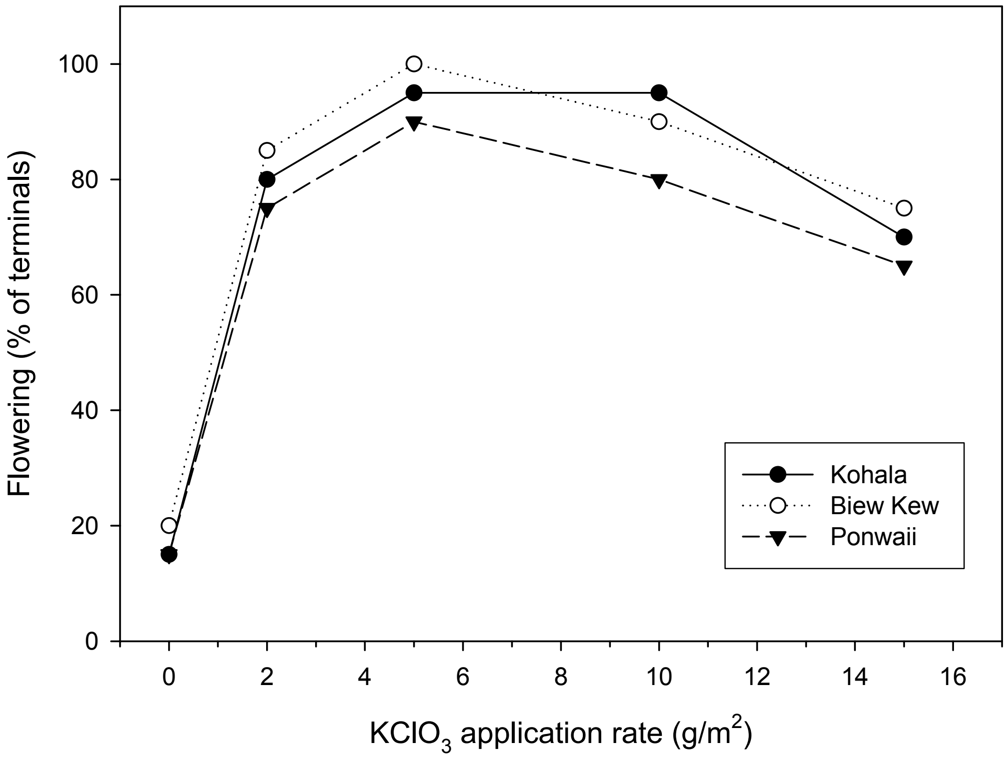

Figure 3.1 Effect of KClO3 application rate on flowering % of three varieties of longan (Kohala, Biew Kew and Ponwaii).

Flowering was best around 5-10 g/m^2 although only slightly lower at 2 and 15 g/m^2. The highest rate seemed to delay flowering slightly (2-3 weeks) and flowering was not quite as uniform as the other treatments. Trees remained in good health following treatment, with just a small amount of leaf senescence (leaf yellowing) of the oldest leaves (5-10%) increasing slightly with the higher rates of application. There was no difference in the level of flowering observed in the trees with and without the leaf litter removed from under the trees, so it would appear that as long as the $KClO_3$ is watered in following application it is unnecessary to remove the leaf litter from under the trees.

The trial work on methods of application (Table 3.1) indicate that collar drenches, spot application, partial root application, trunk and root injection whilst effective at stimulating good flowering in excess of control untreated trees they tend to be less effective than the same rates applied evenly under the canopy.

Table 3.1 Method of $KClO_3$ application and level of flowering induced (averaged across varieties)

Treatment	Flowering %
Control	10-20%
Evenly spread under the canopy (5 g/m^2)	95%
Evenly spread under ½ of the canopy (5 g/m^2)	75%
Spot application (5 g/m^2)	80%
Collar drench (5 g/m^2)	70%
Trunk injection (1 g/m^2)	20-30%
Root injection (1 g/m^2)	20-30%

Partial root applications and spot application resulted in flowering over the entire canopy indicating that the flowering stimulus is probably moved in the transpiration stream to the terminals in the tree. The trunk and root injections were not very effective at stimulating good flowering. This could be due to the low rate of application used (≈ $1g/m^2$) or the lack of direct contact of the $KClO_3$ with the fine root tips or shoot tips thought to be responsible for producing the flowering signal. The expense, time and difficulty of applying the $KClO_3$ through trunk and root injection would also limit its usefulness.

The results of the foliar application of $KClO_3$ trials are shown in Table 3.2.

Table 3.2 The level of flowering (% terminals flowering) and leaf drop caused by various rates of foliar $KClO_3$ application.

	Variety							
	Kohala		Biew Kiew		Chompoo		Homestead	
Rate of $KClO_3$	% flower	Leaf drop	% F	Leaf drop	% F	Leaf drop	% F	Leaf drop
Control	10	5	10	5	5	5	10	5
0.05%	10	0	30	5	35	5	15	5
0.1%	25	10	50	10	70	15	40	10
0.2%	70	15	90	10	90	10	60	15
0.5%	85	20	90	25	90	20	90	20
1%	95	30	100	35	100	35	95	25

Trees of the 4 varieties Kohala, Biew Kiew, Chompoo and Homestead were all very responsive to $KClO_3$ applied as a foliar spray. Rates of 1% resulted in excessive leaf drop (up to 35%). Chompoo and Biew Kiew were the most sensitive varieties. The leaf drop is mostly confined to the older leaves and is worse in trees in poor health. The $KClO_3$ seems to promote premature aging and senescence perhaps resulting from the hormonal changes occurring in the plant triggering flowering. The rates of leaf drop decreased as the concentration of $KClO_3$ applied decreased. As with ground applications flowering (panicle emergence) occurred 7-9 weeks following application.

For the varieties Biew Kiew and Chompoo a rates of 0.2% is recommended as a compromise between good flowering and minimum leaf drop. While in the more vigorous varieties (Kohala, Homestead) a rate of 0.5% is required to trigger good flowering. Results also indicate that rates need to be adjusted for tree health – using higher rates for trees in very good health and slightly lower rates for trees in poor health to avoid excessive leaf drop. Where only part of the canopy was treated with foliar $KClO_3$ only that part of the canopy flowered with the untreated part behaving as untreated control trees. This indicates that the flowering signal triggered by the $KClO_3$ application can be produced in the shoots or roots but can only move throughout the tree in the transpiration stream i.e. from the roots.

Foliar applications would have the following advantages over ground applications:-

- Easy to apply.
- Low rates can be used (≈10% of that required for ground application).
- Unevenly sized trees are not a problem because the foliar rate stays the same, where as ground applications need to be varied for canopy size.
- The position of the crop on the tree can be regulated by only applying the $KClO_3$ to the parts of the canopy where you would like the crop to be. For example the crop could be positioned where it is the easiest and cheapest to harvest, where it is least likely to be damaged by birds and bats, by only cropping part of the canopy the need for fruit thinning is reduced.

The main disadvantage is the leaf drop caused by high rates and the need to adjust the rate for tree health.

5. Effect of methods and rates of application of Potassium Chlorate on previously treated trees.

5.1 Introduction

With repeated use of $KClO_3$ it has been observed both here and overseas that the flowering response often declines and the trees become less sensitive to $KClO_3$. These trials studied the effect of rates and methods of repeat applications of $KClO_3$ on flowering for a range of varieties. Ground applications and foliar applications were studied.

5.2 Materials and Methods

For all treatments trees were split into two groups – those conducive to natural flowering and those not conducive to natural flowering. Conducive trees are those with lots of mature dormant flush and little active vegetative growth. These trees will usually have only been lightly pruned following harvest, have low leaf nitrogen levels (≤ 1.7%), have reduced moisture availability (perhaps even mild water stress) to try and prevent the trees from flushing. These conditions are most likely to exist during the cool winter period when longans flower naturally. The non-conducive trees had a high percentage (≥ 40%) of terminals still actively flushing and these had only recently matured. These trees may have been pruned heavily following harvest, have high leaf nitrogen levels (≥ 1.7%) and are being supplied with plentiful water and nutrients. These conditions are most likely to occur in spring and summer when trying to induce out of season flowering.

The trees used for these trials were 10 -15 years old and 4 x 5m – 6 x 7m in size, growing and managed as described in the materials and methods.

In experiment 1 the treatments consisted of a range of rates and methods of application on the varieties Biew Kiew, Chompoo, Ponwaii and Kohala. The rates used were 0, 2, 5, 10, 15 and 20 g/m^2 of the canopy area. While the methods used were evenly broadcast under the canopy (2m radius from the trunk), a spot application ($1m^2$) under the tree canopy, a collar drench around the trunk, broadcast over only ½ the area under the canopy. Following all treatments the $KClO_3$ was thoroughly watered in. Treatments consisted of 2-3 single tree replicates. Following treatments the overall level of flowering (% of the terminals) and tree health were recorded.

In the second experiment trees of the varieties Biew Kiew, Chompoo, Ponwaii, Kohala and Homestead were treated with foliar KClO3 until runoff. The rates used were 0, 0.2, 0.5 and 1.0%. Treatments were applied to two groups of trees as before-conducive and non-conducive to flowering. Treatments consisted of 2 – 3 single tree replicates. Following treatments the overall level of flowering (% of the terminals) and the level of leaf drop was recorded.

5.3 Results and Discussion

The results for experiment 1 are presented in Table 4.1. In the conducive trees, the control trees flowered quite well (30-60% of terminals flowering), as expected. However, flowering in the control trees was later by about 4 weeks, less uniform and the panicles were generally smaller and weaker than in the trees treated with $KClO_3$. There was no improvement in the level of flowering triggered with the $2g/m^2$ rate, however, flowering did improve with $5g/m^2$ and again increased with $10g/m^2$ to almost full flowering (85-95% of terminals flowering). From these results, it appears that the sensitivity to $KClO_3$ has decreased compared with the first application (where 2-5 g/m^2 was enough to trigger maximum flowering compared to $10g/m^2$ this time) and therefore higher rates need to be used on repeat applications.

Beyond 10g/m^2, the flowering response did not improve and in fact, the flowering seemed to decline slightly at the highest rate (20g/m^2). In all treatments it took 6-8 weeks for the panicles to emerge from the date of application. Applying the $KClO_3$ to the ground as either a collar drench or spot application, resulted in a slight improvement in the flowering response over the 5g/m^2 applied evenly over the ground. This was most probably due to the $KClO_3$ being more concentrated in a smaller area and therefore acted like a higher rate. This was particularly true in the non conducive trees (see below). The treatments where the $KClO_3$ was applied to only half of the root system did not improve the flowering response over the control trees.

In the non conducive trees, (Table 4.1) flowering in the untreated controls was very poor (0-10%) as expected. In these non-conducive trees, even rates of 10g/m^2 $KClO_3$ only resulted in partial flowering (15-30%). The higher rates of 15g/m^2 and 20g/m^2 improved the flowering response further but still did not result in full flowering. There did not appear to be any detrimental effects of the high rates on tree health. In this non conducive state, the trees had further lost their sensitivity to $KClO_3$ compared with the 1st application and full flowering was hard to achieve even with very high rates. Partial flowerings are not ideal because the crop still has to be managed, watered, fertilised, netted, picked and packed but the yields are low, thereby increasing the costs of production. With partial crops, there also appears to be competition between the developing crop and vegetative growth to the detriment of the crop. As before, the collar and spot applications improved flowering slightly over the same rates applied evenly under the canopy, perhaps due to the more concentrated level of $KClO_3$ in the smaller area of application thereby acting like a higher rate.

A comparison of varieties indicates that they all behave in a similar manner. It would appear that Biew Kiew and Chompoo flower more easily than Ponwaii which flowers more easily than Kohala.

The results from the foliar application of $KClO_3$ are presented in Table 4.2. In the conducive trees, the flowering in the control trees was pretty good as expected. The flowering response was improved using foliar $KClO_3$. Using 0.2% for the varieties Biew Kiew and Chompoo and 0.5% for Kohala resulted in a good improvement in flowering without causing excessive leaf drop. As with the ground applications, the sensitivity to $KClO_3$ seems to have declined from the first application with the recommended rate increasing from 0.2% to 0.5%. The high rate (1.0%) caused unacceptably high levels of leaf drop and burnt shoot tips in all varieties. The amount of tree damage varied with the condition of the trees at the time of spraying, lush, healthy trees showed little tree damage (leaf drop, leaf burn) while less healthy trees had a lot of damage. The leaf drop appears to be caused by a hormonal response within the tree rather than a burning response to $KClO_3$. The older leaves gradually turn yellow and senesce over a 3-6 week period. Young healthy leaves are unaffected. Usually the plant growth regulators, ethylene and abscisic acid are associated with senescence.

In the non conducive trees, (Table 4.2) flowering was very poor in the control trees and even with high rates of foliar $KClO_3$ only partial flowering could be triggered. It would appear that when trees are not in a conducive state to flower, foliar applications of $KClO_3$ are less effective at forcing flowering than ground applications. Less leaf drop occurred in these non-conducive trees compared with conducive trees, most probably due to their more active vegetative growth. It is possible that with higher foliar rates, flowering may have been improved, however, this would most likely be associated with more tree damage, leaf drop and burnt shoot tips. It would appear therefore, that foliar applications are not suitable for triggering flowering in non conducive trees.

The comparison between varieties again indicates Biew Kiew and Chompoo are the easiest (most sensitive) to trigger flowering in, while Kohala is the most difficult.

Table 4.1: Effect of the method of application of $KClO_3$ on flowering (% terminals) in a range of longan varieties in conductive and non-conductive states for natural flowering.

	Varieties							
	Biew Kiew		Chompoo		Ponwaii		Kohala	
Method of Application	Conductive.	Non Conductive	Conductive.	Non Conductive	Conductive.	Non Conductive	Conductive.	Non Conductive
Control (no KClO3)	40-60	10	30-40	5-10	40-50	0-5	40	0-5
$2g/m^2$	60	5	30	5-10	40	0-5	40	5
$5/gm^2$	40	5-10	70	10-15	60	5-10	60	5
$10g/m^2$	95	20-30	85	10-25	90	30	85	15-20
$15g/m^2$	95	40-50	85	60	95	40	90	40
$20g/m^2$	90	50-80	80	50-70	80	40-50	80	50-60
Colar ($5g/m^2$)	65	15	70	15	50	15	50	10
Spot ($5g/m^2$)	50	15	60	20	65	10-20	65	10-15
½ Root Zone ($5g/m^2$)	40	5	50	10-15	40	20	30	5-10

Table 4.2: Effect of different foliar $KClO_3$ concentrations on flowering (% terminals) in a range of longan varieties in conductive and non-conductive states for natural flowering.

	Varieties							
	Biew Kiew		Chompoo		Homestead		Kohala	
Method of Application	Conductive.	Non Conductive	Conductive.	Non Conductive	Conductive.	Non Conductive	Conductive.	Non Conductive
Control	40-60	0	30-60	5	-	0-5	40	0-5
0.2%	85	5	80	0	-	0	30-50	0
0.5%	80	10-20	100	15-20	-	0	80	0-5
1.0%	95*	25-45#	90*	20-35#	-	10-15	80*	5-20
					-			

* - Very high leaf drop (20-40%) following application; # - Minor leaf drop (5-10%) following application.

6. Influence of flush age on the flowering response to Potassium Chlorate application

6.1 Introduction

From the previous chapter it was determined that on the second and subsequent applications of $KClO_3$ the flowering response is variable and depends to a large extent on how conducive the trees are to flowering. One of the factors determining how conducive a tree is to flowering would appear to be the stage of vegetative growth in the tree. Observations during the course of this research provide plenty of evidence that the stage of vegetative growth around normal flowering time, or the time of $KClO_3$ application plays an important part in how easily trees flower, for example, a) Trees flower most easily during the winter months when vegetative growth would be dormant and least easily during the summer months when trees are actively growing, b) Trees heavily pruned with lots of active vegetative growth often don't flower or flower poorly, even with $KClO_3$ application, c) Usually the best flowering responses to $KClO_3$ occurs when flowering is triggered quickly (6-8 weeks) following application suggesting that flush growth on the trees needs to be in a state ready to start growing immediately following $KClO_3$ application. A mature dormant shoot, high in carbohydrate, is most likely to be able to start growing reproductively quickly compared to a shoot already growing vegetatively at the time of application and therefore need to change to a reproductive state.

6.2 Materials and Methods

To investigate the role of flush age on the flowering response to $KClO_3$ on second and subsequent applications four trials were conducted.

- In the first trial the effect of the age of vegetative growth and the level of flushing was studied by pruning 10 year old (5m x 5m) trees of cultivar Kohala at four different times over a one year period – August, January, April and June. The amount of vegetative growth and the level of flushing and flowering were then observed over the next two years. Trees were heavily pruned using pneumatic secateurs and 1.5 – 2.0 m of growth was removed from the tops and sides of trees at the time of pruning. Trees were treated with 8 g/m2 KClO3 in June each year.

- In the second trial the relationship between the level of flushing (% of terminals) and the level of flowering triggered (% of terminals) with KClO3 application was studied. Trees of the variety Biew Kiew (8 year old, 5 x 4m) were treated with a 0.5% foliar application of KClO3 in February to try and trigger an early out of season flowering. At the time of application the flush growth on the tree was recorded as either dormant mature, recently matured or actively growing. Eight weeks after application, the level of flowering was recorded as the % of terminals on the tree flowering.

- In the third experiment the influence of flush age (or stage of growth) on the flowering response to KClO3 was studied by tagging branches on trees (variety Kohala) at various stages of growth and applying KClO3. The shoot growth was divided into four stages 1 emerging shoot – brand new flush <15cm (bronze, red in colour) 2 recently matured flush – leaves still shiny, light green in colour 3 mature flush – leaves dull dark green in colour 4 mature flush with no growing point – the shoot tip has either died, is insect damaged or has been removed through pruning at harvest and the shoot has not flushed since. See plate.5.1. The KClO3 treatments consisted of ground applications of 5 g/m2 or 15 g/m2 of the canopy or foliar applications of 0.2 or 0.8%.

Stage 1

Emerging Shoot

Stage 2

Recently matured shoot

Stage 3

Mature dormant shoot

Stage 4

Mature shoot with no growing point

Plate 5.1. The four stages of shoot growth used to classify flush development.

- In the fourth trial the effect of the level of pruning following harvest (January) on the subsequent flowering triggered with $KClO_3$ in (July-August) was studied. Major branches on (12 year old, 6m x 7m) trees of the variety Kohala were pruned with a mechanical pruner at different levels – 2m, 1m, 0.5m and no growth removed. Approximately five months later (June) trees were treated with 10 g/m^2 of $KClO_3$ in June and the level of flushing and flowering observed.

6.3 Results and Discussion

Trial 1
During the first flowering season (2003) following pruning there was no flowering recorded on the trees pruned in January, April or June. The active vegetative growth still occurring in these trees when the $KClO_3$ was applied prevented the trees from flowering. In the trees pruned in August 2002 the vegetative growth had started to slow down (20% young flush) and a reasonable flowering response was recorded. In the control trees in which there was no active growth at the time of $KClO_3$ application the flowering response was very good (Table 5.1).

In the following flowering season (2004) the flowering response was very good in the control trees and those pruned in August 2002 and January 2003. However, flowering was still less on the later pruned trees which still had some active growth at the time of $KClO_3$ application.

Table 5.1: The effect of pruning date on the level of growth, flushing and flowering over the following two years.

	August 03			August 04		
Pruning Date	**Growth (cm)**	**Flushing (% terminals)**	**Flowering (% terminals)**	**Growth (cm)**	**Flushing (% terminals)**	**Flowering (% terminals)**
Control (unpruned)	40	0	80-90	100	0	90-100
August 02	80	20	20-30	140	0	100
January 03	30	70	0	120	10	95-100
April 03	10-20	80	0	100	10	60-80
June 03	5	100	0	80	30	40-60

The results indicate that following heavy pruning it can take two years for the vegetative growth to return to normal levels. While trees are actively regrowing following pruning the flowering response is severely reduced even with $KClO_3$ application.

Trial 2
In general the flowering response of all trees was poor due to most of the treated trees being in a relatively active stage of growth at the time of treatment and the flowering stimulus provided by the 0.5% foliar $KClO_3$ application was relatively weak. The weak relationship between the amount of mature flush on the trees at the time of application and the level of flowering figure 5.1 (r^2=0.44) is most probably due to not being able to accurately measure the age of the mature flushes. Due to the time of year (warm temperatures and high rainfall) even the mature flush has probably only recently matured and growth has not stopped completely (dormant). Also other factors such as leaf nitrogen levels, starch levels in the tree and the previous cropping are likely to influence the level of flowering in the trees.

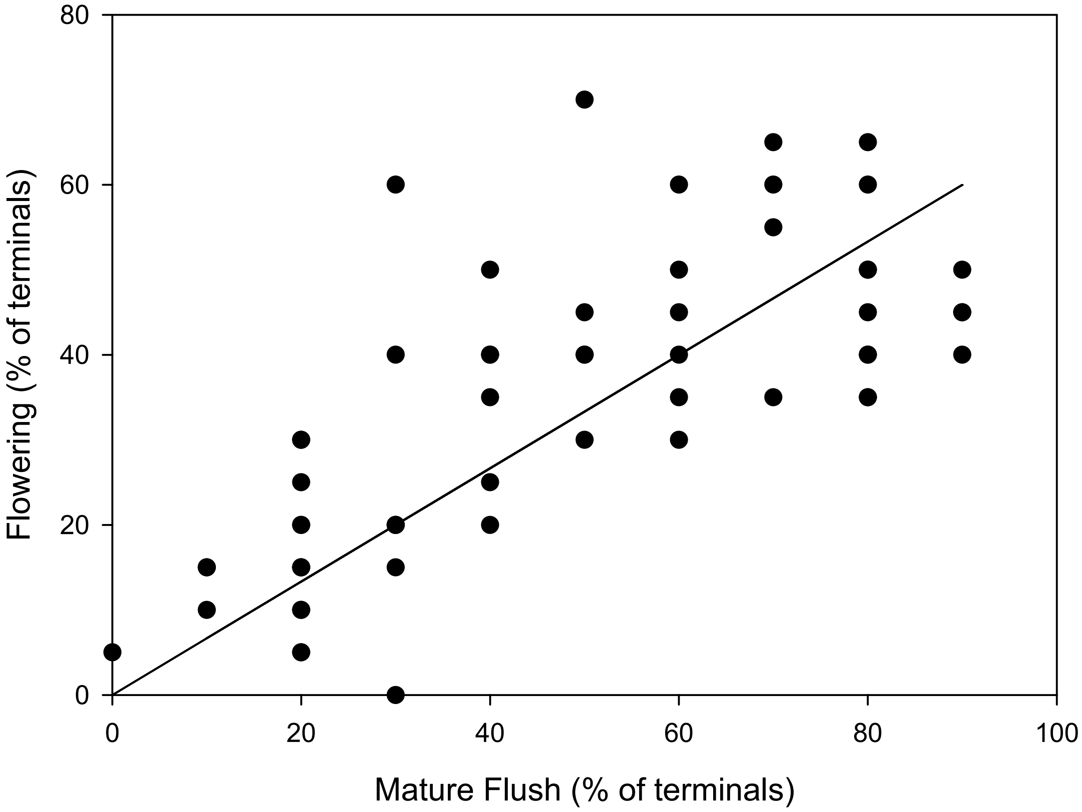

Figure 5.1. The relationship between % mature flush and level of flowering in Biew Kew following foliar treatment with $KClO_3$ (0.5%). Regression significant at ($P \leq 0.05$).

Trial 3

The results indicate that flowering can be triggered in shoots at any stage of growth. However, the mature dormant shoots (Stage 3) followed by the recently matured shoots (Stage 2) flower more easily than shoots with new young flush growth (Stage 1) or in shoots without a growing tip (Stage 4). (See plate 5.1). The flowering response was best with ground application of $KClO_3$ verses foliar applications. In the foliar applications because the flowering stimulus was weak the flush age is more important in determining the flowering response. The flowering response improved with the higher rates of application particularly in the shoots in Stage 1 and 4 in which flowering is normally poor. This indicates that in trees with a lot of shoots in these stages of growth higher rates of $KClO_3$ will need to be applied to achieve reasonable flowering compared to trees with lots of mature flush (Table 5.2).

Table 5.2: The flowering response (% terminals flowering) of different stages of flush growth to $KClO_3$ application

Stage of Flush Growth	**$KClO_3$ Application**			
	Ground		**Foliar**	
	5 g/m^2	**15 g/m^2**	**0.2%**	**0.8%**
1	10%	30-60%	1-10%	20-50%
2	30-60%	50-70%	10-35%	40-60%
3	60%	90%	30%	30-80%
4	20-40%	40-50%	0-20%	20-30%

Shoots with mature dormant flush were the fastest to respond to the $KClO_3$ and had the largest panicles. Panicles developing from terminals in Stages 1 and 2 of growth were slower to develop, usually smaller and leafier than those developing from terminals from dormant mature shoots (Stage 3). These leafy panicles often resulted in poorer fruit set and fruit development. The leafy panicle would seem to indicate that the $KClO_3$ has caused the shoot tip to revert from a vegetative state to a reproductive state. In the shoots with no growing point (Stage 4) when flowering occurred it was the auxiliary side shoots which developed and flowered these tended to be slower to develop than panicles developing from the terminal shoots.

Although flowering was best from mature dormant shoots (Stage 3) some flowering occurs in all stages of shoot growth This indicates that factors other than the stage of shoot growth also control flowering, for example leaf nitrogen, tree and shoot carbohydrate levels, position of the shoot in the tree (sun exposure). The variation in flowering response between shoots with mature flush may also be related to the length of time the shoots had been dormant. In this trial the mature flush may have just entered dormancy or may have been dormant for several months. Other observations indicate that shoots which have been mature for 4-8 weeks flower more easily than shoots which have just reached maturity. This is an important consideration in achieving good flowering and explains why it can be difficult to get good flowering in trees with high leaf nitrogen, or heavily pruned or during summer months. Under these conditions vegetative growth remains active and shoots flush repeatedly never allowing flushes to stop growing, enter dormancy and mature before the next growth flush. In winter when cool temperatures and low rainfall are not conducive to flushing, flush growth may stay mature and dormant for several months prior to flowering.

Trial 4

The results from trial four are shown in Table 5.3. The branches that were heavily pruned (2m and 1m growth removed following harvest) were still actively growing and had the youngest flush growth at the time of the $KClO_3$ treatment and only very poor flowering was triggered (5-10%). In the control trees in which no growth was removed and in the treatment where only 0.5 m of growth was removed there was little or no active growth in the branches at the time of $KClO_3$ application and the level of flowering was much better (40-60%). In these branches, shoots flushed only once and then remained dormant. These results demonstrate that the level of pruning following harvest plays a critical role in the level of subsequent flowering. This would appear to be related to the strength of growth or the amount of recent growth in the branches prior to the $KClO_3$ application. Therefore the flowering response is likely to be poor following heavy pruning even in trees treated with $KClO_3$ due to the vigorous vegetative growth stimulated. This indicates that only parts of the orchard should be heavily pruned at a time so that some production can be maintained.

Table 5.3. The effect of severity of pruning following harvest on subsequent flowering ($KClO_3$ treated $10g/m^2$)

Amount of growth removed (m)	Flowering (% of terminals)
2.0	5-10
1.0	10
0.5	40-50
0.0	60

7. Effect of Leaf Nitrogen on the flowering response to Potassium Chlorate.

7.1 Introduction

Longan trees with high leaf nitrogen have been observed not to flower as well as trees with low leaf nitrogen (Diczbalis, 2002, Menzel et al., 1999). This is thought to be related to the influence nitrogen has on the balance between vegetative growth and reproductive growth, with high leaf nitrogen promoting vegetative flushing at the expense of flowering. Leaf nitrogen is also thought to play a role in the flowering response to $KClO_3$ on repeat application.

7.2 Materials and Methods

To test this, the leaf nitrogen levels at the time of $KClO_3$ treatment and the level of flowering triggered was recorded on trees (variety Kohala) treated with $KClO_3$ (5-10 g/m^2) over several properties over three years in the Mareeba Dimbulah Irrigation Area. The level of flowering was estimated by recording the % of terminals flowering.

7.3 Results & Discussion

The results indicated that although the flowering percentage was inversely related to leaf nitrogen levels the link is quite weak (r^2 = 0.465). Only 46.5% of the variation in flowering could be explained by changes in leaf nitrogen concentration (Figure 6.1). This result is not unexpected with other factors such as the previous flowering/cropping history, the rate of $KClO_3$ used, level of pruning, flush development and climatic factors (temperature) also influencing the flowering response.

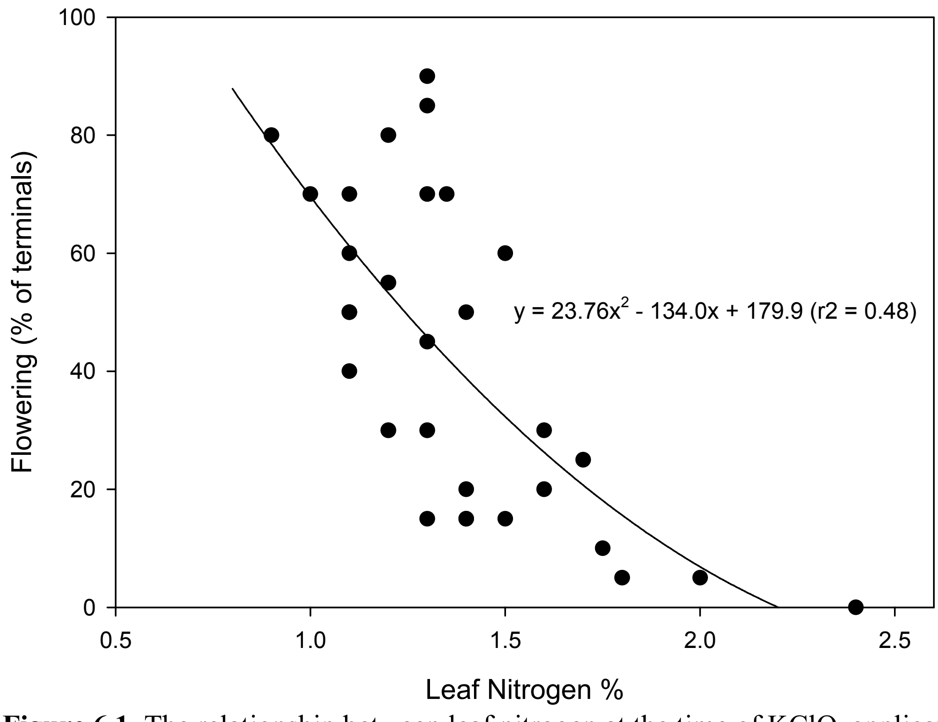

Figure 6.1. The relationship between leaf nitrogen at the time of $KClO_3$ application and the level of flowering (% terminals flowering) induced by $KClO_3$ application (5-10 g/m^2). Regression significant at ($P \leq 0.05$)

The results indicate that in the trees with leaf nitrogen levels above 1.7% the flowering response is nearly always poor (0-25% of terminals flowering), suggesting that high leaf nitrogen can over-ride other factors influencing flowering including the rate of $KClO_3$ application. Where trees were given extra soil nitrogen and irrigation during the normal flowering season to stimulate vegetative growth and discourage flowering was very poor. Between 1.2% and 1.5% leaf Nitrogen flowering was generally better but quite variable ranging from 20% - 80% of the terminals on the tree flowering. Below 1.2% leaf nitrogen, the flowering response is nearly always good with 40-80% of the terminals flowering.

Although low leaf N seems to promote flowering it is generally agreed that good nutrition is essential for good crop production so that low leaf N should only be temporarily induced to aid flowering. Similarly if flowering is trying to be delayed, temporarily increasing leaf N will help to keep the tree in a vegetative state and reduce flowering. Because of the carry-over effect of soil applied N, foliar applications may be more suitable to prevent flowering, as it allows the tree levels to decrease more quickly, which will help flowering to be induced at a later stage.

Although low leaf nitrogen concentrations leading up to flowering may enhance flowering %, its important to balance this with the need for nitrogen during fruit filling. Longan fruit contain relatively high concentrations of nitrogen relative to the two other commercial members of the Sapindaceae family (lychee and rambutan) Diczbalis (in press).

8. The use of heat-sums to predict harvest dates following potassium chlorate application

8.1 Introduction

The ability to initiate and manipulate flowering with $KClO_3$ allows flowering of longans, to be triggered outside of the normal flowering season (July – September). Fruit maturity following normal flowering will occur approximately six-eight months (180-220 days) from flowering, depending on variety. Out of season flowering will result in differing times to maturity due to different temperature regimes during the maturity period. When $KClO_3$ is used to trigger flowering in longan the flowering time can be manipulated to almost any time of the year which results in a range of ripening times because fruit developing during warmer months matures faster then when it develops in cooler months. Knowing how long fruit will take to mature from different $KClO_3$ application dates would be very valuable to growers as it would allow them to time their applications with market opportunities, e.g. Chinese New Year, periods of low volumes or periods of high prices.

The aim of this trial was to develop a technique to accurately predict when fruit will be harvested following application of $KClO_3$. The technique can also work in reverse. That is, the grower can nominate a preferred harvest time and the date of application of $KClO_3$ can be calculated.

8.2 Materials and Methods

Trials were conducted to measure how the application date of $KClO_3$ influenced the harvest date (time to mature). Observations of application dates and subsequent harvest dates were recorded across a number of properties over a number of years in the Mareeba Dimbulah Irrigation Area on the Atherton Tablelands inland from Cairns. Information was collected for the cultivars Kohala and Biew Kiew. Temperature data from two orchards using an automatic weather station which recorded temperature every hour was used to calculate a heat sum for the orchards in question.

Heat sum data or growing degree days is a summation of the mean temperature required to complete a biological process, in this case fruit development. The sum of the growing degree days for each day from application date to harvest date is the number of growing degree days required to mature a crop. The base temperature is the temperature at which it is estimated no development occurs (in this case 12°C). The base temperature is the temperature above which growth (floral development, flowering and fruit development) occurs, hence the formula discounts temperatures below 12^{o}C because they do not contribute directly to growth. The base temperature of 12^{o}C used in this project was an estimate based on work conduced on mango (Schaffer et al. 1994) a crop from a similar ecophysiological region.

The heat sum calculations reported were based on the following formula;

Growing degree days = (daily maximum temperature °C + daily minimum °C)/2 - 12°C (base temperature).

8.3 Results and Discussion

The effect of date of application of $KClO_3$ on days to mature is shown in Figure 7.1. Biew Kiew fruit takes between 216 days (≈ 7 months) and 286 days (≈9½ months) to ripen depending on the date of $KClO_3$ application, compared with 182 – 268 days (6 – 8½ months) for Kohala. Hence the development time from flowering to ripening is 18-34 days longer in Biew Kiew than Kohala.

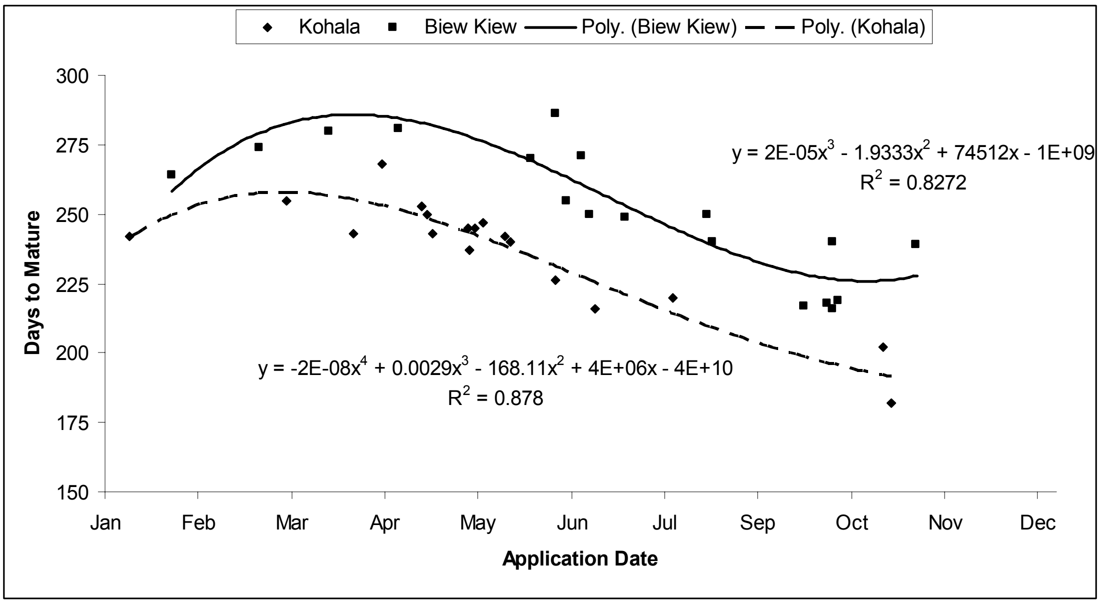

Figure 7.1. The effect of application date of $KClO_3$ on days to fruit maturity for longan (cv. Kohala and Biew Kew). Observations are based on several seasons and locations across the Atherton Tablelands. Polynomial relationships are significant at $P \leq 0.05$.

The fastest fruit development coincides with harvest dates from April to May where fruit development occurs through summer and into early autumn the period of highest mean temperatures (October – may) while the slowest period of fruit development occurs from March to October when mean monthly temperatures are their lowest (Figure 1.1).

In Figure 7.2 the application date has been plotted against the harvest date. The relationships derived from this data be used to time applications with market opportunities e.g. if Chinese New Year was in mid January (period of high demand and prices) then $KClO_3$ should be applied in mid March for Biew Kiew and mid May for Kohala, so that fruit is harvested at this time.

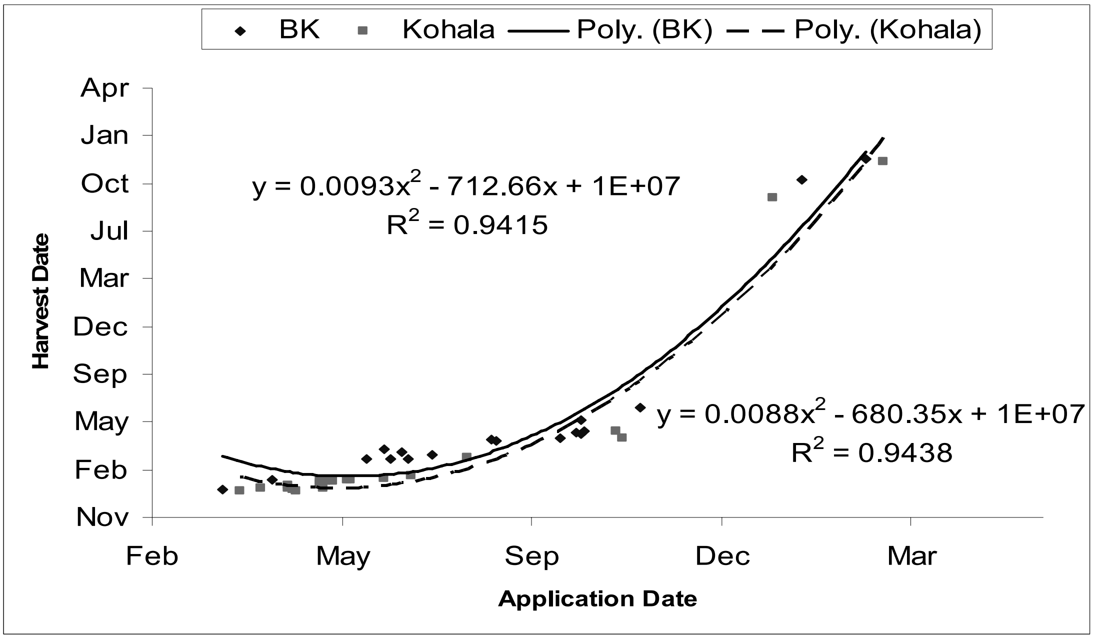

Figure 7.2. Longan harvest month for varieties Kohala and Biew Kiew following application of $KClO_3$. The polynomial curves used to describe the relationships are significant at $P \geq 0.05$.

The variation between the time to mature from the same application dates is caused by the variation in the actual temperatures from year to year. In a year with above average temperatures fruit development could be 1 – 2 weeks faster than normal and in a cooler than normal year fruit development could be 1 – 2 weeks slower than normal. Therefore, to help predict the maturity date with more certainty in a particular year at a particular location a heat sum can be calculated, using the maximum and minimum temperatures and a base temperature.

In Tables 7.1 and 7.2 the growing degree days and the calendar days for a crop to reach maturity from different application dates is shown for cv. Kohala and cv. Biew Kiew.

Table 7.1 shows that the number of growing degree days to mature a crop in cv. Kohala is quite consistent ranging between 2642 and 3006 growing degree days, this compares to the very large range in calendar days (182-268). Using heat sums to predict harvest date is more accurate then calendar days because it uses a combination of actual temperatures during fruit development and time, hence the units "growing degree days". The advantage of this method can be seen for the October application dates. In 2001 it took 182 calendar days for the crop to mature compared with 202 days in 2002. So that if the results from 2001 had been used to predict maturity date for 2002 an error of 3 weeks would have occurred. Whereas there were only 97 growing degree days difference between 2001 and 2002 or about 7 days (assuming a maximum temperature of 32^0C and a minimum of 20^0C) i.e.

$(32°C + 20°C)/2 – 12 = 14$ growing degree days/day $\therefore$ 97 divided by 14 = 6.9 days.

So that if growing degree days had been used to predict maturity date in 2002 an error of only 7 days would have occurred.

Table 7.1: Growing degree days (base temperature 12°) and calendar days for longan fruit (cv. Kohala) to reach maturity from different application dates of $KClO_3$

Application Date	First Harvest Date	Growing degree days	Days to first harvest
04/05/01	02/01/02	2948	243
18/05/01	10/01/02	2940	237
19/06/01	31/01/02	2985	226
23/10/01	23/04/02	2909	182
30/04/02	08/01/03	2947	253
17/05/02	17/01/03	2887	245
20/10/02	10/05/03	3006	202
15/04/04	08/01/05	2936	268
04/07/04	05/02/05	2850	216
31/05/03	28/01/04	2875	242
23/05/04	25/01/05	2642	247
Mean		**2902.3**	**232.8**
S		**29.5**	**7.4**
CV%		**3.4**	**10.6**

Table 7.2: Growing degree days (base temperature 12°) and calendar days for longan fruit (cv. Biew Kiew) to reach maturity from different application dates of $KClO_3$

Application Date	First Harvest Date	Growing degree days	Days to first Harvest
20/09/03	24/04/04	3408	217
1/10/03	4/05/04	3409	216
3/10/03	9/05/04	3451	219
21/04/04	27/01/05	3516	281
15/07/04	21/03/05	3431	249
29/09/04	5/05/05	3319	218
29/06/03	26/03/04	3464	271
19/06/04	1/04/05	3456	286
Mean		**3431.8**	**244.6**
SE		**20.2**	**10.9**
CV		**1.7**	**12.6**

In cooler climates $KClO_3$ application may be less effective in manipulating harvest date than in warmer climates. With cool temperatures the winter months contribute very few growing degree days toward the crop maturity so that even a 3 – 4 month difference in application date may result in only 1 – 2 weeks difference in maturity date. This is because all the heat to mature a crop in a cool climate occurs in the summer months and almost none in the winter months e.g. A winter day with a maximum of 20^0C and a minimum of 6^0C will only contribute 1 growing degree day toward the maturity of the crop, compared to the 3000 required to mature the crop .i.e.

$(20°C + 6°C)/2 – 12 = 1$ growing degree day.

Therefore, it is concluded that a warm growing climate offers more opportunity for manipulation of flowering and harvest dates with $KClO_3$. During these trials no discernable difference in fruit quality (size, brix and colour) from a range of harvest dates was observed.

Some other considerations in manipulation of flowering/harvest times are -

It was also observed that the time taken for fruit to mature was also influenced by the crop load on the tree. In young trees with low crop loads or on larger trees which have been heavily thinned (see thinning trial Chapter 7) fruit tended to mature up to 2 – 3 weeks ahead of trees with larger crop loads.

$KClO_3$ tends to work best when used around the normal flowering time, so getting out of season cropping can be difficult.

Early Flowering
Triggering good early flowerings is more difficult than later flowering. If trees flower poorly while trying to trigger early flowering there is a risk they will flower again during normal flowering time and there will be two uneven crops developing on the trees needing careful and extended management. To get early fruit maturity trees have to be treated very early because fruit development is slow through the winter months. Trees have to be treated in February to March for ripening around Christmas (Figure 7.2) which is often not very successful if the trees have just been harvested and the climate is conducive to fast vegetative growth (hot and wet). The long crop development phase also means the trees/crop has to be managed for longer allowing more opportunities for things to go wrong and increasing the costs. Another problem encountered with early flowering on some varieties e.g. Kohala has been poor pollination if the trees flower when it is cold. This has resulted in nubbins in the panicles reducing quality and increasing labour costs in packing.

Late Flowering
Delaying flowering to delay maturity also has its difficulties. In order to delay flowering it is necessary to restrict natural flowering which can be done with varying degrees of success with plentiful water and nitrogen application to promote vegetative growth at the expense of reproductive growth – however this can then make achieving late flowering difficult.

Delaying flowering will shorten the crop development stage which may reduce the costs of production and will give the tree more time to recover before flowering the following year. A possible disadvantage could be that the flowering time may overlap with very hot dry conditions (Oct-Nov) which may effect fruit set and increase fruit drop if sufficient water and humidity can't be kept up to the trees. Some fruit drop may be an advantage to help reduce the crop load where heavy flowering has been triggered.

Summary
Heat sum calculations show the importance of temperature in determining the speed of fruit development hence length of crop maturity. It allows individual growers to more reliably determine harvest dates for trees treated with $KClO_3$ at different times of the year. This allows growers to reliably plan for labour, packing and transport requirements. At an industry level the technique would allow a group of growers to coordinate fruit supply to ensure that the market is not flooded with fruit which results in low prices. However, the technique is only as good as the flowering response to $KClO_3$ application which as outlined in previous chapters is reliant on a number of factors.

9. The effect of root pruning and the chemical growth retardant paclobutrazol applied post pruning on subsequent vegetative growth and flowering in longan.

9.1 Introduction

In terminal flowering trees where a series of successive vegetative flushes usually precedes flower or panicle emergence there is continuous competition between vegetative and reproductive growth forms. In mature longan trees it is commonly understood that appropriate management is needed to regulate vegetative and reproductive growth cycles. Wong (2000) suggests that trees should be limited to one or two vegetative flushes between harvest and the next flowering. In chapter 5 it was shown that it can take up to two years for flowering to occur following heavy pruning.

In commercial longan orchards controlling vegetative growth is critical for 2 reasons. Firstly to control tree size which aids management operations for example harvesting, spraying and netting. It is also important for encouraging flowering either naturally, or artificially with $KClO_3$. In Chapter 5 it was observed that the flowering response was improved in shoots which had matured and stopped growing compared to those still flushing. In this trial root pruning and a chemical growth retardant were used to investigate if vegetative growth could be controlled in pruned longan trees.

9.2 Materials and Methods

A commercial block of longan trees (cv. Kohala, 8 x 6 m spacing) were heavily pruned in May 2004 using a mechanical pruner, 2.5 m of growth was removed from the tops and sides of the trees. In the week following pruning four treatments were applied to five trees in non replicated blocks. The treatments were

1. Root pruning – roots were cut to a depth of 30 - 40 cm, 2.0 m from the trunk parallel to the row.
2. Chemical growth retardant (paclobutrazol 0.5%); 4 monthly foliar sprays commencing in August 2004 after maturity of the first vegetative flush.
3. Combination of root pruning and paclobutrazol foliar sprays.
4. Untreated control

Tree regrowth measurements commenced in July prior to the first application of paclobutrazol. Regrowth was measured in two ways. Firstly, whole canopy regrowth was measured by recording canopy cover at 2.0, 2.5 and 3.0 m from the tree trunk on both sides of the trees. A GRS Densiometer® was used to measure the presence or absence of canopy cover at 2.0, 2.5 and 3.0 m from the tree trunk at right angle to the row direction identified by permanent pink dyed markers inserted in the ground on 11 occasions from July 2004 to October 2005. The data for each tree was accumulated and the mean count for each treatment and standard errors calculated.

The second measurement of growth was conducted by tagging two shoots per side of each tree giving 20 shoots/treatment, and monitoring flush type and length from September 2004 to October 2005. From this data the following flush attributes were calculated;

- Average number of flushes prior to flowering

- Average length of vegetative flushes
- Percentage of tagged shoots which flowered and set fruit
- Percentage of tagged shoots which remained vegetative
- Average length of flowering shoot at full panicle extension

Yield data was to be collected in February 2006. However, this did not eventuate as final fruit set in all treatments was low and as a consequence the orchard was not netted and the remaining fruit was lost to bird and bat pests.

9.3 Results and Discussion

Canopy regrowth

Following pruning the edge of canopy was less then 2.0 m from the trunk. Figure 8.1 shows the development of canopy cover at 2.0 m, 2.5 m and 3.0 m from the trunk or centre line of the row.

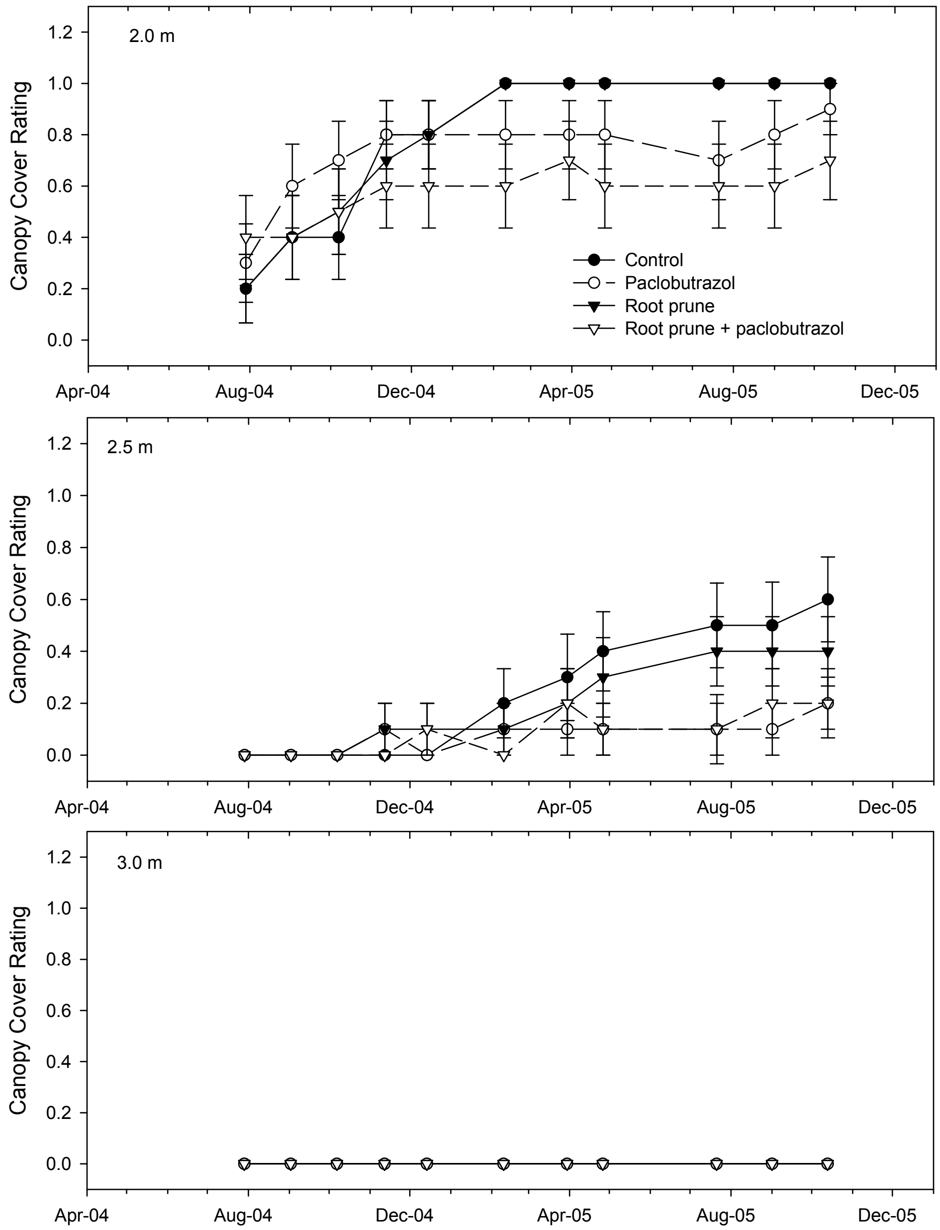

Figure 8.1. Canopy cover ratings for control, foliar paclobutrazol and root pruning treatments and the combination at 2.0 m, 2.5 m and 3.0 m from centre line of the tree row following pruning in May 2004. A canopy cover rating of one is equivalent to full canopy cover. The vertical bars represent the SE.

The canopy cover ratings showed that none of the treatments reached the 3.0 m mark in the 17 months from pruning. At 2.5 m from the trunk, canopy recovery was most advanced in the control trees and least advanced in the paclobutrazol and paclobutrazol + root pruning treatment. The canopy recovery of root pruned trees was intermediate. Canopy cover at 2 m from the trunk was clearly reduced in the paclobutrazol and paclobutrazol + root pruning treatment. Both the control and root pruning treatments reached full canopy cover at 2.0 m 6 months after pruning.

The data suggests that four paclobutrazol foliar sprays did control overall canopy vigour.

Flush length and phenology
Data from the tagged branches indicates that there was little difference between treatments for the average total shoot number produced over a 17 month period following pruning (Table 8.1). The foliar paclobutrazol, by itself or in combination with root pruning reduced but not significantly the flush number relative to control or root pruned trees. No treatments influenced the proportion of reproductive to vegetative shoots with approximately 50% of tagged stems e flowering.

Table 8.1 Effect of root pruning and paclobutrazol applications on flush number and length and flowering capacity (17 months after pruning)

	Control	Paclobutrazol	Root Prune	Root Prune + Paclobutrazol
Average number of flushes from tagging.	3.6	2.9	3.8	3.1
% tagged shoots – reproductive	50.0	45.0	50.0	45.0
Average length of flowering shoots (mm)	630	617	743	569
S.E.	± 61	± 103	± 55	± 91
Average length of vegetative shoots (mm)	557	255	613	358
S.E.	± 103	± 38	± 114	± 74

Data on mean total shoot length for flowering and vegetative shoots is shown in Table 8.1. Due to the large variation in shoot length measured the standard errors are large and essentially there is no significant difference in average total shoot length between treatments. However, Table 8.1 shows mean total length of vegetative shoots treated with paclobutrazol are approximately 250 to 300 mm shorter then non paclobutrazol treated shoots. For flowering shoots there was no difference in mean length possibly due to the fact that the last paclobutrazol application would have had no effect on panicle length (because it was sprayed 7 months earlier so the effects had finished) and hence the normal panicle growth masked any differences in growth that occurred prior to the onset of flower emergence.

9.3 Summary

This trial has demonstrated that foliar paclobutrazol applications can reduce the number and length of flushes following heavy pruning, while root pruning had no effect. Neither treatment had any effect on the level of flowering.

10. Bearing Capacity or the relationship between fruit load and fruit size.

10.1 Introduction

With the use of potassium chlorate trees are cropping more heavily and consistently than previously experienced. Heavily bearing trees are very prone to overbearing which without appropriate thinning of the crop load has resulted in small poor quality fruit with low brix levels and subsequent tree decline. If trees are badly effected, cropping is reduced in the subsequent one to two years, tree health can take several years to recover or in extreme cases it can result in tree death. Overbearing has therefore highlighted the importance of fruit thinning in a production system using $KClO_3$.

10.2 Materials and Methods

A trial was designed to determine the level of thinning required to produce good yields of high quality large sweet fruit. Trees flowering heavily from the use of $KClO_3$ were thinned to remove between 0 and 75% of the panicles (crop load). Whole panicles were removed and the remaining panicles cut in ½ to ⅓. Panicles were removed when fruit was pea sized (4-5mm) to allow for natural fruit thinning to occur. Data was collected on yield, fruit size, brix levels and maturity date.

The trials were conducted on two groups of trees, 6 year old (4 x 4m) Kohala trees and 15 year old (5 x 5m) Biew Kiew trees growing on commercial orchards under a high degree of management (plentiful irrigation and nutrition).

Biew Kiew

Six uniform trees with 125 – 150 panicles/tree with an estimated crop of over 200 kg/tree were selected. Panicles were thinned and reduced in size to remove approximately 25, 40, 50, 55, 60 and 70% of the crop load. No control trees (unthinned) were left because experience suggested that with such a large crop load the fruit would not size properly and tree health would suffer.

Kohala

Eight uniform trees with approximately 150 panicles with an estimated crop of over 200 kg/tree were selected. Flower panicles were thinned and the remaining ones halved to remove approximately 0, 45, 65 and 75% of the crop load (two trees of each).

Fruit were measured during crop development and harvested when maximum size and sweetness was reached.

10.3 Results and Discussion

For Biew Kiew the results are presented in Figure 9.1 and 9.2. These show that fruit size increased and the yield decreased with increasing levels of fruit thinning. Fruit size did not increase significantly above 55% thinning, indicating that thinning beyond this level is not warranted. The increase in fruit size (hence weight) helps to compensate only a small amount for the loss in yield associated with the increasing thinning, so that the decline in yield from 167 kg/tree to less than 100 kg would have to be weighed against the improved fruit quality (size), earlier maturity and market prices, to determine its merits. Fruit on the heavily thinned trees ripened 2 – 3 weeks earlier than on the less thinned trees.

For these trees it is estimated that they had a canopy surface area of $40m^2$ which indicates that these trees are able to support a around 3 kg of fruit/m^2. On these heavily flowering trees this will mean removing around half of the panicles.

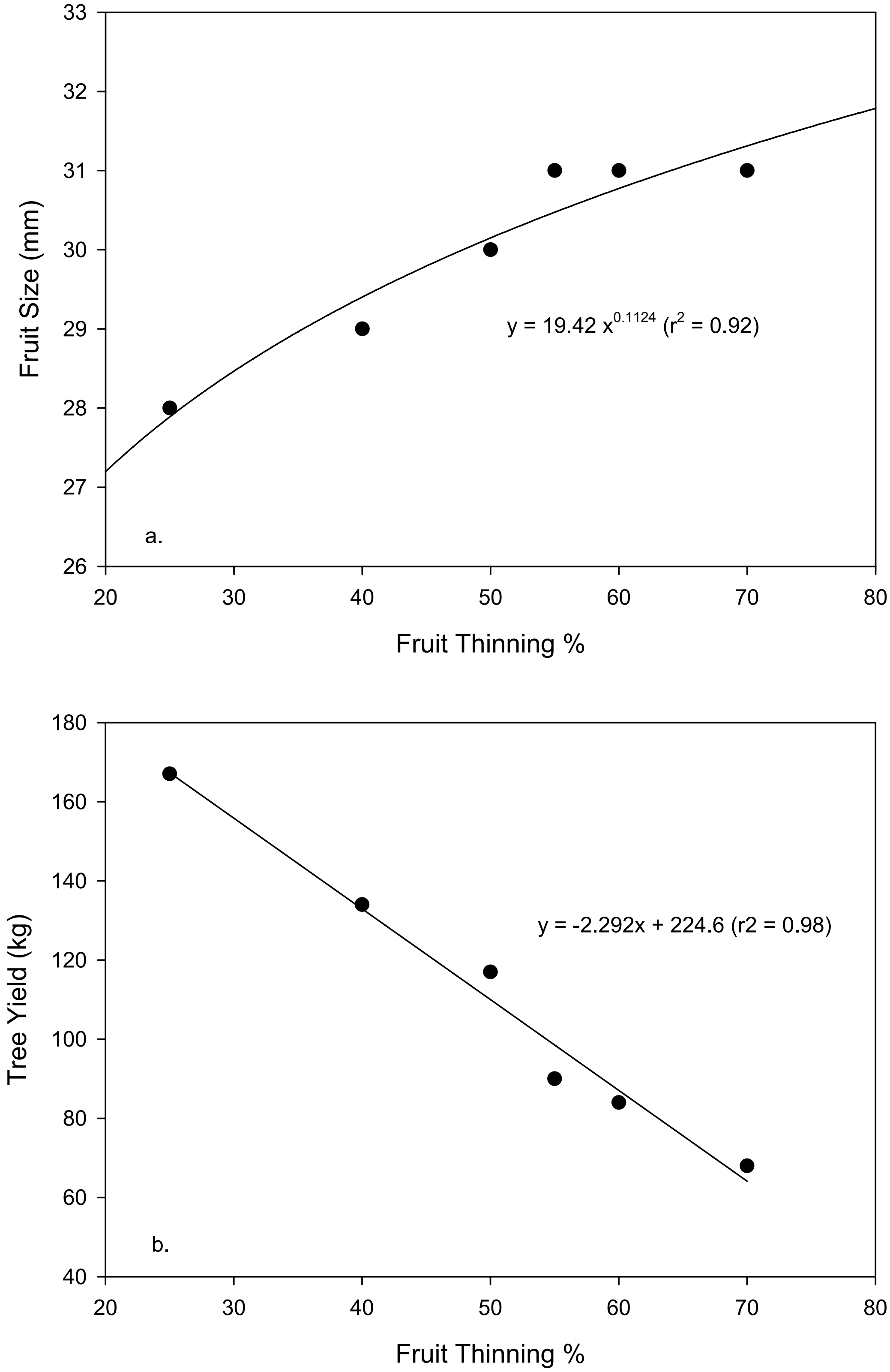

Figure 9.1. Effect of fruit thinning in longan (cv. Biew Kiew) on a). fruit size (mm) and b). tree yield.

The results for the Kohala trees are presented in Table 9.1. The trees with no thinning produced only small fruit with low brix readings and were un-marketable. Trees with no thinning also showed a decline in health with a lot of yellowing leaves and some leaf drop. Trees with higher levels of thinning remained in good health throughout crop development; fruit ripened earlier were larger and sweeter.

The increase in fruit size with thinning (6g to 17g) helps to compensate for the loss in numbers of fruit to some extent however total yield is still dramatically reduced. The results indicate that for these trees a level of fruit thinning of around 45% is essential to produce good quality well-sized sweet fruit. The decline in yield from 136kg/tree to 110kg/tree and 85kg/tree with increasing thinning needs to be weighed against the improvement in fruit size, brix level and earlier maturity and market prices. For these trees it is estimated that they had a canopy surface area of $25m^2$ which indicates that the trees are able to support and size around 4-5kg of fruit/m^2 or 3 – 4 panicles/m^2. On these heavily flowering trees this requires removing around 50% of the panicles.

Table 9.1 Effect of fruit thinning in longan (cv. Kohala) on fruit weight (g), fruit size (mm), brix and tree yield (kg).

Level of Thinning (%)	Fruit Size (g) Average	Fruit Size (mm) Average	Brix (%)	Yield (Kg)
0	6.0	21	13	200
45	12.6	25	17	136
65	13.9	29	18.5	110
75	17.2	31	19	85

There is no doubt that panicle pruning results in improved fruit size and fruit quality as measured by brix. Pruning longan panicles to enhance fruit size and reduce the onset of biennial bearing patterns is a relatively common practice in longan growing countries. Wong, (2000) reports that in Thailand longan growers reduce the number of flowers by half (each flower spike is retained) before fruit set. After fruit set they remove 10% of the fruit. Wang et al. (2004) report that in China longan (cv Shixia) panicle thinning results in larger fruit with higher pulp recovery and total soluble solids. They recommend that at least 50% of flower panicles should be removed. Crane (2005) recommends that in heavy flowering years at least 40 to 50% of panicles should be removed followed by removal of half the length of the remaining panicles.

The results from these studies confirm that longans grown under Australian conditions react similarly to those overseas. As a general rule of thumb, in heavily flowering crops up to 50% of panicles should be removed with a further reduction of fruit numbers if fruit set is high.

11. Conclusion / Recommendations

Research work from this project has demonstrated that the chemical Potassium Chlorate ($KClO_3$) is a powerful flowering inducing agent in longan trees (flowering occurring around 6-8 weeks after application). Ideal rates, timings and methods of application have been determined as well as guidelines for crop thinning and crop maturity forecasting. Controlling vegetative growth was unsuccessful using root pruning but foliar sprays with paclobutrazol did reduce vegetative growth.

Results indicate similar responses across cultivars, soil types and climates. When used for the first time, trees are very sensitive and flower very easily at low rates (5-10 g/m^2 of the canopy applied to the ground or 0.2% applied as a foliar spray). Trials on methods of application indicate that the $KClO_3$ should be spread reasonably evenly under the tree canopy and watered in. Foliar applications only induce flowering in the parts of the canopy which have been sprayed unlike the ground applications which translocate through the whole tree. Trees are more easily damaged (leaf drop and shoot tip burn) by the foliar applications and rates need to be kept less than 1%. On the second and subsequent applications trees become less sensitive to the $KClO_3$ and rates need to be increased (10-20 g/m^2 of the canopy applied to the ground or 0.5-1.0% applied as a foliar spray). As well trees need to be carefully managed on the second application so that they are in a condition ready to flower i.e. low leaf nitrogen (<1.5%) and a lot of mature dormant vegetative growth with little or no active flushing. This is easiest to achieve during the normal flowering season (winter) and difficult to achieve following pruning and in the hot wet summer months.

The predictive formula developed in this project using heat sums will allow growers' to predict the harvest date from the application date of $KClO_3$ so that cropping can be timed with market opportunities which will lead to improved prices and economics of production.

With the increasing use of $KClO_3$ trees are being cropped more heavily than ever before which has led to problems of over bearing and poor quality fruit. Work from this project has indicated that in trees with full flowering, 40-60% of the panicle should be removed from the trees as even under good management they are only capable of supporting 3-5 kg of fruit/m^2 of the canopy surface area.

Mode of Action

The flowering response to potassium chlorate is so rapid (6-8 weeks from application) and so dramatic that it suggests that the response is induced by hormonal changes within the plant. The early and gradual (3-6 weeks) senescence of the older leaves in the canopy also suggest a hormonal response (possible ethylene or abscisic acid). Other research has found other oxidising compounds e.g. hypochlorite, hypochlorate, Na chlorate and Ca chlorate can also induce flowering (although not as well) while other potassium compounds e.g. KCl, KNO_3 don't induce flowering. This suggests that it is the oxidising effect of the chlorate that must initiate the hormonal changes in the plant responsible for the flowering.

Flowering can be triggered with ground or foliar application while flowering is poorest from trunk and root injection. These findings suggest that the hormonal response is most likely produced in the growing points i.e. shoot tips and root tips, which are the usual centres of plant hormone production. With ground applications the flowering response translocates throughout the whole tree suggesting the flowering stimulus is transported in the xylym or transpiration stream. Where foliar applications are used only the parts of the canopy sprayed flower suggesting that although the flowering stimulus can be produced in the shoot tips it cannot be transported from them in the phloem.

The loss of sensitivity to $KClO_3$ could be due to two factors – either the sites for production of the flowering stimulus are reduced (e.g. damage to the fine root hairs from previous application) or on the second application a higher threshold of the flowering stimulus is required to change the shoot from vegetative to reproductive. Although shoots of all stages of growth can flower in response to $KClO_3$ application the mature dormant shoots and those exposed to the most sunlight, flower most easily and hence have the smallest requirement for the flowering stimulus to flower.

The findings from this research project have led to a much better understanding of the efficient and effective use of $KClO_3$ for triggering flowering in longan. The close association with the industry during the conduct of this project through research trials, farm visits and association meetings mean the findings are being readily adopted.

11.1 Implications

This project has led to a much better understanding of the efficient and effective use of Potassium Chlorate for the triggering of flowering in longan. The close association with industry during the conduct of this project has meant the findings are being readily adopted.

With the effective use of $KClO_3$ the industry can look forward to consistent and improved flowering and cropping year after year which should greatly aid the economics of production and industry viability. This will have flow on effects of increasing the size and value of the longan production area which in turn will boost the economies of the regional communities where longans are grown.

Longan production was characterised by huge fluctuations in production varying dramatically from year to year (from 200 tons up to 1500 tons). However, now yields are likely to stabilise at around 1500-2000 tons/year worth $7.5-10m. Being able to time production by manipulating the flowering time is also likely to have huge economic benefit. Rather than all of Australians production flooding the market over a few months resulting in over supply and poor prices, it can now be spread more evenly over the whole year, improving market prices received by the growers and making longans more available to consumers which is likely to increase their consumption.

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13. Rambutan

13.1 Background

The rambutan (*Nephelium lappaceum L.*) is a tropical fruit and member of the Sapindaceae family closely related to the lychee and longan. The rambutan is considered to be a native of west Malysia and the island of Sumatra (Indonesia). van Welzen and Verheij, (1991) report that the origin is untraceable because escapees from cultivation blur the original distribution. They claim the species ranges from southern China down through the Indo-Chinese region and the Philippines. The crop is now grown in a number of locations outside its natural distribution including Central America, Sri Lanka, India, New Guinea, tropical Africa, Hawaii and northern Australia.

Seedling rambutans were first introduced into Australia in the 1930's and commercial plantings commenced in the 1970's (Watson 1988). From the early 1970's to 1988 fifty-one cultivars were imported into Australia and underwent preliminary evaluation at Kamerunga on the out skirts of Cairns (Watson, 1988).

Australia produces between 500 to 1,000 tonnes of rambutan per annum from approximately 32,000 trees on 150 ha. The main commercial varieties in Australia include; R9, R134, R156(red), R162, R167, Binjai, Jitlee and Rongrien. The variation in production is a result of seasonal variation and management. The bulk of plantings (22,000 trees) are located from Cooktown to Tully. A smaller industry (≈ 8,000 trees) is based in Darwin, NT. The industry supplies fruit mainly to buyers of Asian descent in the State capital cities with an increasing demand from Australians of European decent, particularly those who have travelled extensively or lived in SE Asia where the fruit is a everyday favourite commonly available from street fruit vendors. The Australian industry has started to focus on overseas markets and a small but growing market is being developed in Japan.

Fruit production in rambutan in north Queensland is susceptible to climatic variations from year to year. The duration of the dry season appears to be the main driving force behind flower initiation, but a cool winter appears to be able to override the drought requirement.

Tree size control, *via* pruning, further complicates the flowering process with many orchardists experiencing a loss in production for a season or two following heavy pruning. Heavy or structural pruning is required every three to four years to allow efficient orchard maintenance and ease of netting to ensure bird and bat control.

Assured flowering, every season, would be of great economic benefit to the industry and the north Queensland rural region as a whole. Regular crop production would allow industries to plan their development and marketing strategies. These industries have included flowering management and tree size control as major production issues within their strategic plans.

The project aims are to:

- Monitor the effect of different pruning dates on shoot development and time to floral initiation
- Test a range of pre-flowering flush control chemical and physical treatments to control flush and enhance flowering
- Trial a range of chemical to burn new unwanted flush

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- Trial the effect of root pruning on vegetative growth and reproductive behaviour
- Test the efficacy of synthetic auxins in altering the sex ratio of flowers.

13.2 Rambutan Literature Review

The rambutan *(Nephelium lappaceum*) is a member of the Sapindaceae family and tropical in nature (Nakasone and Paull, 1998). The rambutan industry is primarily confined to the wet tropical north Queensland coast at latitudes between 16°S and 18°S while approximately 25% of Australia's rambutan production occurs in the wet/dry tropics in the vicinity of Darwin (12°S).

Canopy management and flowering are important determinants of orchard productivity. Orchard performance is based on a range of variables. Two important factors are paramount and include; (1) the initial plant spacing and hence tree density and (2) the annual management inputs which include in the early years tree training and in subsequent years thinning and pruning. Important outcomes from the combination of the above two factors include; light interception and degree of canopy porosity and maintenance of a balance between vegetative and reproductive growth. Rambutan are evergreen trees capable of growing to 10 to 20 m. The tree crown is dense and compact and generally round in shape. Trees are generally formed from a single main trunk which divides into several major branches which then further branch to the level of individual shoots. Growth is rhythmic with new leaves, flowers and fruits forming on terminal shoots. Following fruit harvest there are two to three flushes of vegetative growth with each new flush occurring after leaves of the current flush have matured. The flowering flush which bears an inflorescence usually occurs following a rest phase and coincides with cool/dry weather in rambutan. Pruning (canopy management) following harvest can impact directly on the trees ability to flower and crop in the subsequent season. In traditional growing areas rambutan and were planted as widely spaced trees and pruning was not considered a necessary management options because trees had sufficient room to develop and cropping was opportunistic and linked to favourable weather conditions which promoted flowering.

Rambutan experience irregular flowering, particularly when they are grown outside of their preferred environment (Lim and Diczbalis 1998). The north Queensland production region for these crops is problematic due to a lack of pre-flowering dry weather requirement for rambutan. Excellent cropping can be achieved in some years, however poor flowering or nil flowering in "off" years make management and economic viability difficult for producers.

To further exacerbate the irregular flowering issue, heavy pruning, every three to four years, for tree size control to assist tree management and protective bird and bat netting control measures reduces potential yields in the subsequent year.

Little research has been done on the need for and effectiveness of pruning in longan and rambutan trees, although there is some data on their close relative lychee (Nakasone and Paull 1998). Recent work published by Menzel *et al.* (1999) has reported on "Optimising canopy management in lychee, longan and rambutan". The majority of the work was carried out on lychee. The study found that in lychee, floral induction occurred, in most cases, when buds a few millimetres long grew during cool (temperatures < 20°C) conditions. The researchers then showed that flush development was strongly related to radiation and temperature. A model was constructed which allowed the most appropriate pruning date to be selected for any given latitude which would most likely result in new bud growth under cool conditions. Field testing of the model, from north Queensland to northern NSW showed that it was possible, at higher latitudes, to prune lychee to maintain tree size and promote flowering and cropping due to the more reliable advent of cool conditions. Tip pruning of lychee trees in northern Queensland generally resulted in poor erratic flowering. The research also showed that if a late autumn flush resulted due to warmer sunnier conditions then predicted by the model, hence not maturing until after the period of cool winter weather, the new flush could be removed (desiccated) by the use of ethephon. The loss of the immature flush results in new growth during cool weather increasing the likely-hood of flowering. The research conducted on longans showed that they behave similarly to lychee. However further work is required to test the principles in commercial orchards over a wide range of environments.

In the more tropically adapted rambutan, flushing generally occurs throughout the year with flowering panicles generally developing on a seasonal basis following a dry period. In some parts of West Malaysia where a bimodal rainfall pattern occurs rambutan is reported to give two crops per year with the second crop being much lighter then the main. A three to four week period of drought, which reduces vegetative growth, is generally a precursor to flowering (Diczbalis 1997). Grower observations in the Northern Territory and North Queensland suggest that trees become unproductive following five to six years without pruning. Lost production particularly occurs lower in the canopy where shading from neighbouring tree rows results in branches and shoots with low vigour and subsequent flowering. In far north Queensland pruning trees to reduce height, following harvest, will generally result in lost production in the next season. Work conducted in the Northern Territory (Diczbalis and Wicks, 1998) showed that structural pruning on permanently netted rambutan trees, following harvest in February, resulted in yields approximately 24 % less than non pruned trees. Pruning tended to delay flowering and harvest, but trees were able to flower and fruit within six months of relatively heavy structural pruning.

A range of tree size management treatments have been developed in association with top pruning. Physical treatments such as cincturing and root pruning are both reported to be a means of controlling vegetative growth. Disruption of the phloem as occurs in cincturing has been shown to reduce vegetative growth above the point of cincturing. This often results in improved flowering and fruit set. There are indications that the treatments may be more effective in warmer environments where vegetative growth is not restricted by climate (O'Hare 1989). In olives Ben-Tal and Lavee (1984, cited by Gucci and Cantini, 2000) showed that cincturing can reduce biennial bearing. Cincturing is a common practice in lychee, particularly in China where cincturing in late autumn is used to reduce vegetative vigour four to six weeks prior to flowering (Zang 1997). Recent research in lychee has shown that cincturing applied immediately pre or at early flowering can improve fruit retention (Huang 2001). There is no work reported for rambutan and longan.

Poerwanto and Irdiastuti (2005) reported that cinctured rambutan trees flowered earlier and had more fruit per panicle than uncinctured trees with cincturing increasing the starch content of the tree top relative to that of roots.

Root pruning is widely used in temperate fruits (apples and stone fruits) to restrict above ground vegetative growth in high density orchards (Arzani et al. 1999, Khan et al. 1998, Webster and Ystaas 1998). There is little reported literature on the effects of root pruning on tropical fruit crops. Ismail (1996) showed that root pruning increased flowering in carambola. A SE Queensland lychee grower with an apple growing background regularly root prunes his lychee trees at early flowering (June/July) to stimulate the effect of cincturing at flowering (M. Veens pers com.).

Chemical methods of promoting vegetative dormancy and subsequent flowering abound. In lychee a range of chemicals have been reported to have beneficial effects and include; sodium napthalene acetic acid, daminozide, CCC, ethephon, paclobutrazol and MKP (O'Hare 1989, Nagao and Paull 1998). Similarly in rambutan, paclobutrazol and ethephon have been reported to promote vegetative dormancy and promote flowering (Tindall, 1994).

Flowering in terminal bearing tropical fruit trees is complex and dependent on many interacting factors, such as variety, day/night temperatures, soil water status, sunshine hours, maturity of shoots. Tree pruning management in commercial orchards superimposed on these factors further complicates flowering management. Our understanding of the processes involved in flowering are limited and experience from various growing areas suggests that pruning and associated management techniques need to be developed to suit local varieties and climatic conditions.

14. Effect of pruning date on regrowth, flowering and cropping of pruned and non pruned shoots of rambutan.

14.1 Introduction

Rambutan fruit production in north Queensland is susceptible to climatic variations from year to year with flowering being dependent on the duration of the dry season or a cool winter to be able to override the drought requirement. Tree size control, *ie.* pruning, further complicates the flowering process with many orchards experiencing a loss in production for a season or two following heavy pruning. Heavy or structural pruning is required every three to four years to allow efficient orchard maintenance and ease of netting for bird and bat control.

Assured flowering, every season, would be of great economic benefit to the industry and the north Queensland rural region as a whole. Regular crop production would allow the rambutan industry to plan development and marketing strategies. This project examines the effect of six pruning times (February, April, June, August, October and December) on regrowth, flowering and cropping of both cut stems and the remaining unpruned shoots.

14.2 Materials and Methods

Five rambutan growing orchards were selected spanning the main north Queensland growing areas from Daintree (16^{o}S) to Murray Upper (18^{o}S). On each farm 12 rambutan trees (cv. R134) were selected. Two trees at each site were pruned at bimonthly intervals commencing from February 2003 (Table 11.1). Pruning was applied to external branches and shoots and resulted in approximately 2 to 3 m of the tree being removed (Plate 13.1). The aim of the pruning was to reduce tree height in a way similar to that which occurs by mechanical pruning machines utilised by the industry. Following pruning, ten cut stems and non pruned shoots were tagged on each tree. The diameter of cut stems was measured at the time of tagging and the average stem diameter monitored for regrowth is shown in Table 13.2. The response of tagged shoots was monitored regularly (every 2 to 4 week) and at each visit flush type and flush length were recorded. The flush stage was identified using the criteria shown in Table 13.3.

Table 13.1. Pruning dates for the five locations and six times.

Location	Prune 1	Prune 2	Prune 3	Prune 4	Prune 5	Prune 6
Daintree	17/2/03	17/4/03	4/6/03	11/8/03	8/10/03	17/12/03
Woopen Creek	11/2/03	15/4/03	18/6/03	14/8/03	10/10/03	19/12/03
Innisfail	13/2/03	15/4/03	18/6/03	14/8/03	7/10/03	19/12/03
Silkwood	7/2/03	16/4/03	19/6/03	12/8/03	7/10/03	23/12/03
Murray Upper	19/2/03	16/4/03	17/6/03	13/8/03	16/10/03	18/12/03

Yield data for the 2003/2004 and 2004/2005 season was supplied by growers and is limited in that there are only two replicate trees per location.

Collected data was collated and means and standard error (SE) calculated for flush length, flush stage and tree yield. In this report data from only three of the five growing areas are shown, representing north, central and southern growing regions (Daintree, Woopen Creek and Silkwood).

The average stem diameter of tagged cut stems varied from 8 to 35 mm with the bulk of cut stems in the 10 to 20 mm range (Table 13.2). Observations of shoot regrowth following pruning lead to the observation that in general smaller diameter stems produce new shoots more rapidly then larger stems.

Table 13.2. Average diameter (mm) of cut wood tagged following pruning.

	15-Feb-03	15-Apr-03	15-Jun-03	15-Aug-03	15-Oct-03	15-Dec-03
Daintree	10	35	12	17	19	19
Silkwood	14	8	9	8	11	9
Woopen Creek	12	11	7	8	13	11

February prune Silkwood - before

February prune Silkwood - after

Mechanical pruning of rambutan

Rambutan orchard shortly after mechanical pruning.

Plate 13.1. Examples of hand pruning as carried out in the trial compared to mechanical pruning carried by some sections of the industry.

Table 13.3. Flush stages used to describe tree phenology and associated description and photographs.

Flush Stage	Description	Photograph	Flush stage	Description	Photograph
1	Young buds swollen, green and up to a few millimetres in length.		7	Flowering (anthesis) > 50%	
2	Early flush development, marked by stem elongation.		8	Fruit set	
3	Flush expanding with red-brown stem and expanding pale green to light pink leaflets.		9	Early fruit development	
4	Hardening off, with soft green leaflets		10	Mid fruit development	
5	Mature hard green leaf and bud dormant.		11	Fruit ready to harvest	
6	Panicle emergence				

14.3 Results

Effect of pruning date on flowering and yield
All pruning dates impacted negatively on flowering and yield in the coming season (Table 13.4 and Figure 13.1). Cut shoots flowered less then shoots in the season immediately following pruning. The mean cut shoot flowering percentage was 6.7% and 58.1% for the 03/04 and 04/05 season respectively compared to 18.3% and 57.5% in the non pruned shoots for the 03/04 and 04/05 season respectively. In the season immediately following pruning the flowering percentage was the highest for the earlier pruning treatments (February, April and June). By the 2004/2005 season the flowering percentage of pruned and non pruned shoots was similar at 58.1% and 57.5% respectively. Over both seasons the Woopen Creek location produced the highest flowering percentage for both shoot types.

The final mean tree yields were a reflection of flowering behaviour. The mean seasonal yields for all locations and all pruning dates for the 2003/2004 and 2004/2005 season were 3.1 kg/tree and 25.4 kg/tree respectively.

The highest yield in the season immediately following pruning was from the February pruning (10.3 kg/tree). Later pruning resulted in negligible yields from 0.5 to 3.4 kg/tree whereas the mean yields in the 2004/2005 season ranged from 12.0 kg/tree for the latest pruning time (Dec 03) to approximately 30 kg/tree for the three earliest pruning dates (Feb, Apr and Jun 03).

Effect of pruning date on shoot frequency and length
The effect of pruning date on mean shoot length (mm) and frequency for three locations are shown in Figures (13.2, 13.4, 13.6, 13.8,13.10, 13.12). Shoot development and flushing varies depending on location, shoot type and the time of year pruning took place. In most cases major shoot development (increases in length) occurred during the warmer spring, summer and early autumn period. Shoot development was relatively dormant during the cooler late autumn, winter and early spring period when average temperatures are low. The average number of shoot flushes, over the monitoring period, for both pruned and non pruned shoots decreased from five to two from the February 2003 prune to the December 2003 prune.

The average new shoot length produced following pruning was similar for shoots produced from pruned and non pruned shoots. The production of a new shoot from pruned stems was often delayed relative to the production of shoots produced from non pruned shoots. The delay was generally greatest for the pruning carried out in April and June, in some cases by up to three months.

Shoot stage
The effect of pruning dates on shoot stage is shown in figures (13.3, 13.5, 13.7, 13.9, 13.11, 13.13). A mean shoot stage of six or higher (maximum 11) indicates that the shoots are in a reproductive stage from panicle emergence to harvest. There is little difference between mean shoot phenology for shoots emerging from pruned or non pruned wood. There is a tendency, but possibly not significant, for non pruned shoots to become reproductive ahead of shoots emerging from pruned wood.

Table 13.4. Percentage of tagged stems (pruned and non pruned) which flowered in the 2003/2004 and 2004/2005 season following pruning on six occasions.

	Pruning Dates						
	Feb-03	Apr-03	Jun-03	Aug-03	Oct-03	Dec-03	Location Mean
2003/2004							
Pruned							
Daintree	25	0	0	0	0	0	**4.2**
Silkwood	0	0	25	0	0	0	**4.2**
Woopen creek	25	35	5	5	0	0	**11.7**
Mean	*16.7*	*11.7*	*10.0*	*1.7*	*0.0*	*0.0*	***6.7***
Non pruned							
Daintree	30	0	25	0	0	0	**9.2**
Silkwood	55	0	55	5	0	0	**19.2**
Woopen creek	15	50	10	20	65	0	**26.7**
Mean	*33.3*	*16.7*	*30.0*	*8.3*	*21.7*	*0.0*	***18.3***
2004/2005							
Pruned							
Daintree	10	45	80	90	20	10	**42.5**
Silkwood	40	25	65	70	40	5	**40.8**
Woopen creek	80	90	95	95	100	85	**90.8**
Mean	*43.3*	*53.3*	*80.0*	*85.0*	*53.3*	*33.3*	***58.1***
Non pruned							
Daintree	30	45	70	80	35	40	**50.0**
Silkwood	40	20	40	55	80	10	**40.8**
Woopen creek	85	95	80	75	60	95	**81.7**
Mean	*51.7*	*53.3*	*63.3*	*70.0*	*58.3*	*48.3*	***57.5***
Pruned shoot mean	**30.0**	**32.5**	**45.0**	**43.3**	**26.7**	**16.7**	
Non pruned shoot mean	**42.5**	**35.0**	**46.7**	**39.2**	**40.0**	**24.2**	
Overall mean	**36.3**	**33.8**	**45.8**	**41.3**	**33.3**	**20.4**	

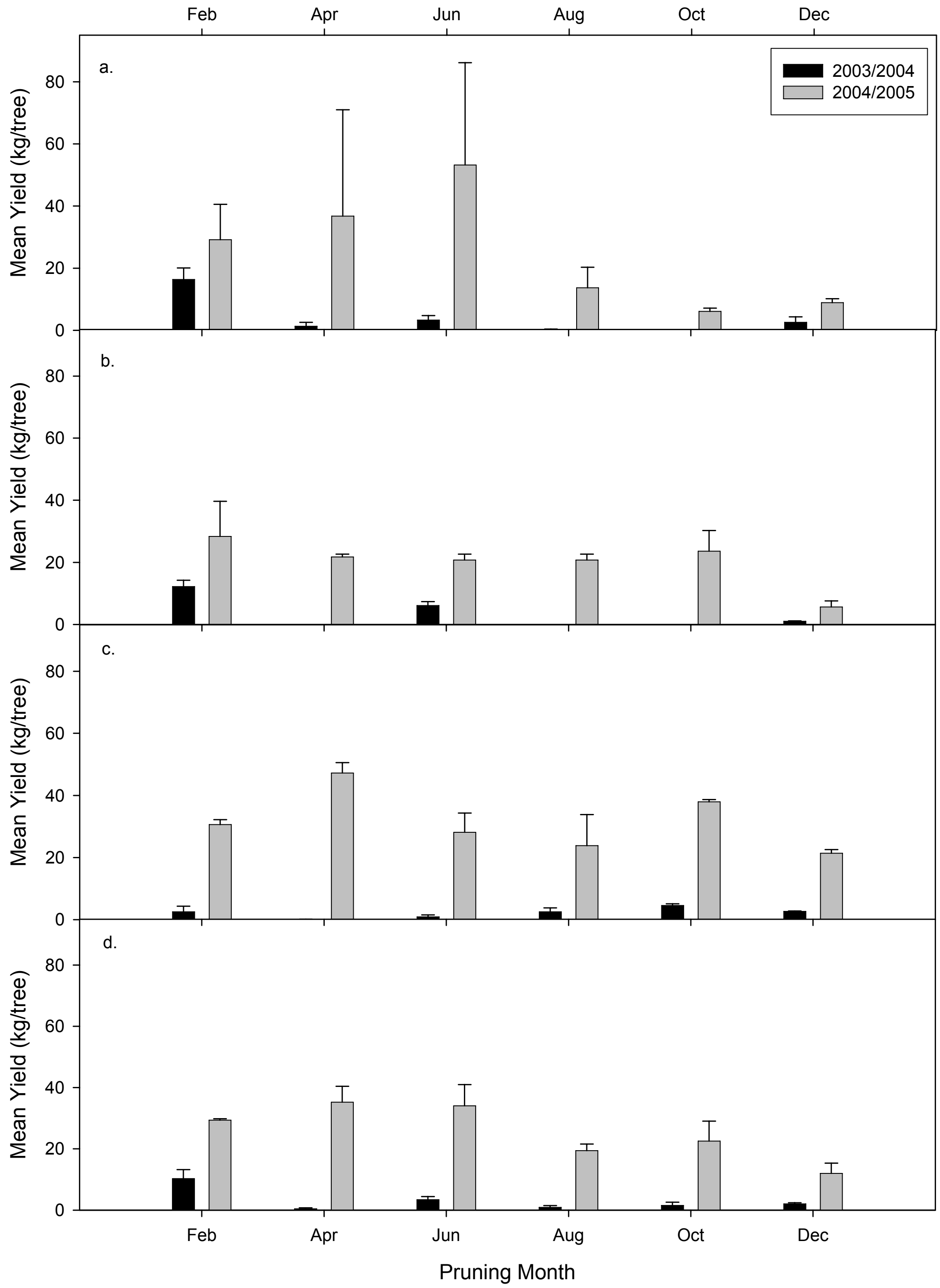


Figure 13.1. Mean rambutan tree yield (kg/tree) for two seasons following six different pruning occasions in 2003 for three locations a. Daintree, b. Silkwood, c. Woopen Creek and d. overall mean. The Vertical bars represent the standard error.

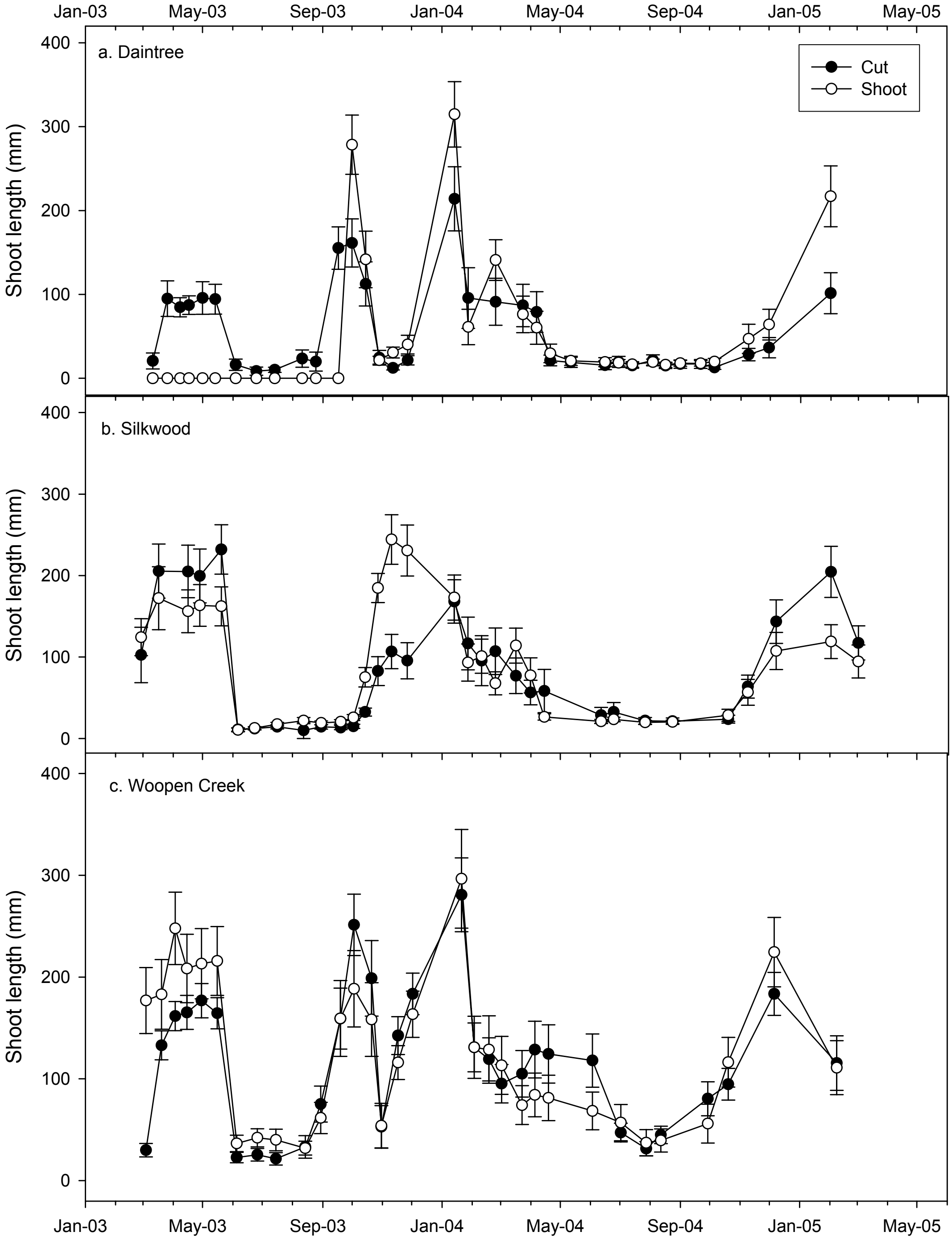


Figure 13.2. Mean shoot length for tagged pruned stems and non pruned shoots following pruning in February 2003. The vertical bars represent the standard error.

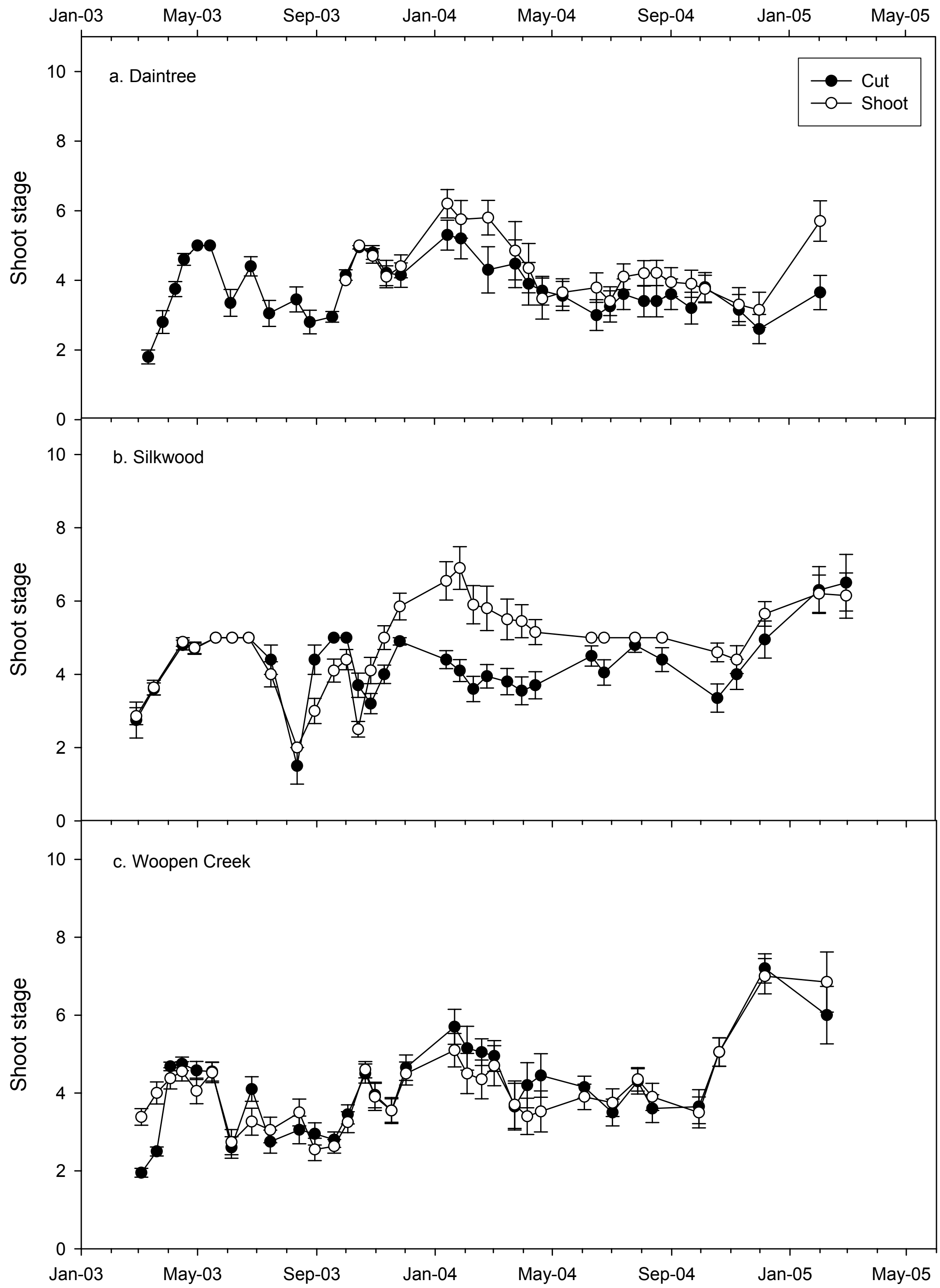


Figure 13.3. Mean shoot phenology stage for tagged pruned stems and non pruned shoots following pruning in February 2003. The vertical bars represent the standard error.

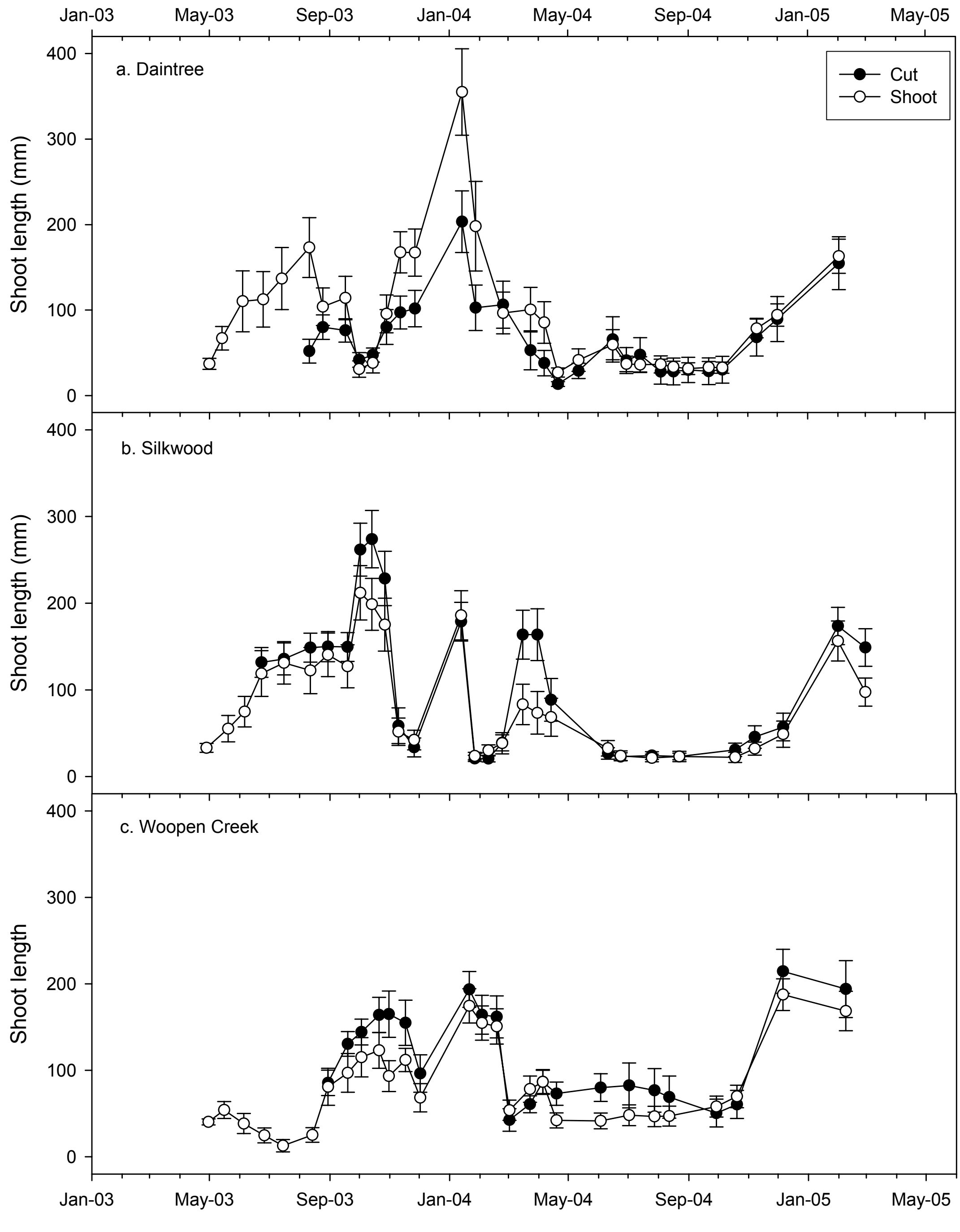


Figure 13.4. Mean shoot length for tagged pruned stems and non pruned shoots following pruning in April 2003. The vertical bars represent the standard error..

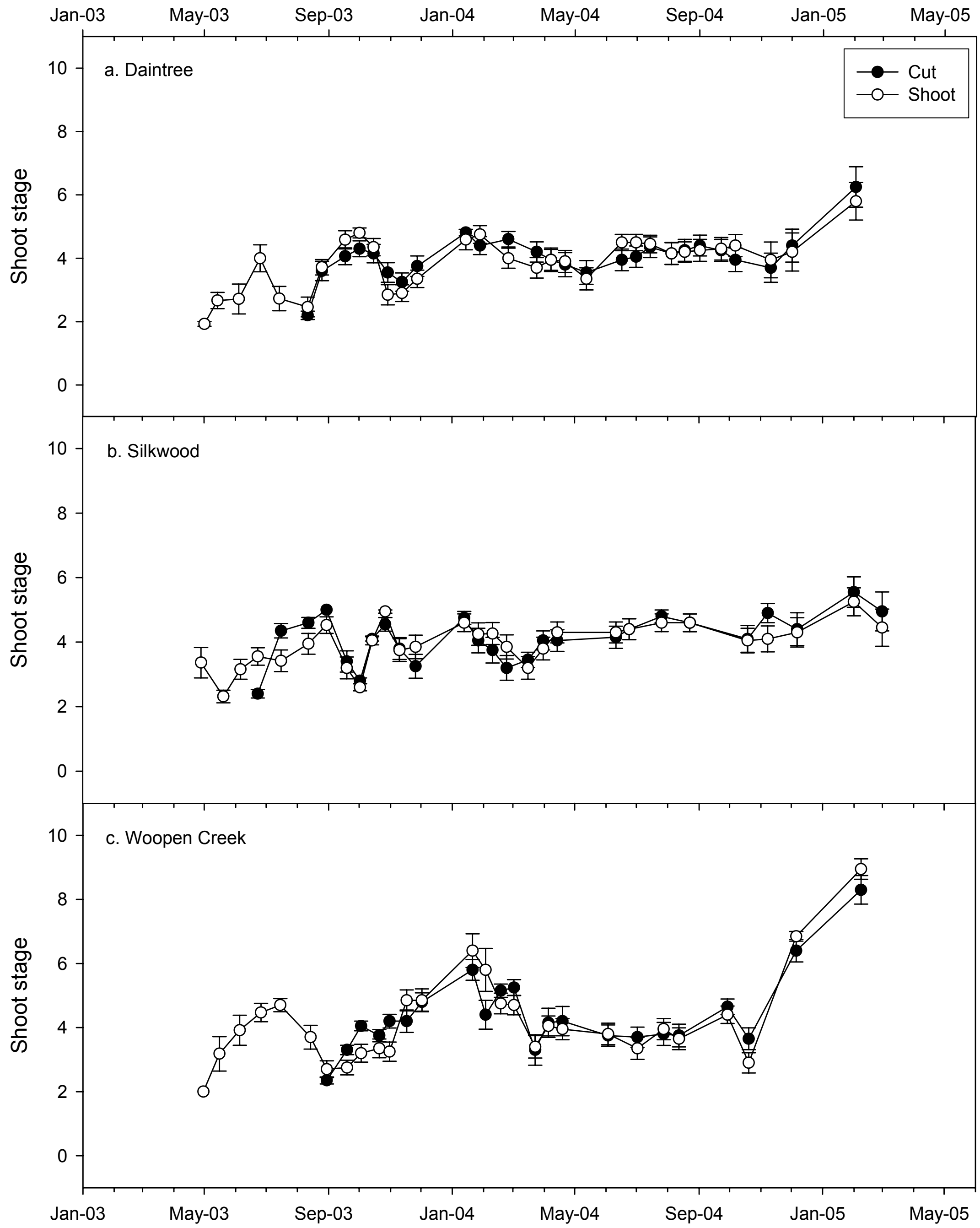


Figure 13.5. Mean shoot phenology stage for tagged pruned stems and non pruned shoots following pruning in April 2003. The vertical bars represent the standard error.

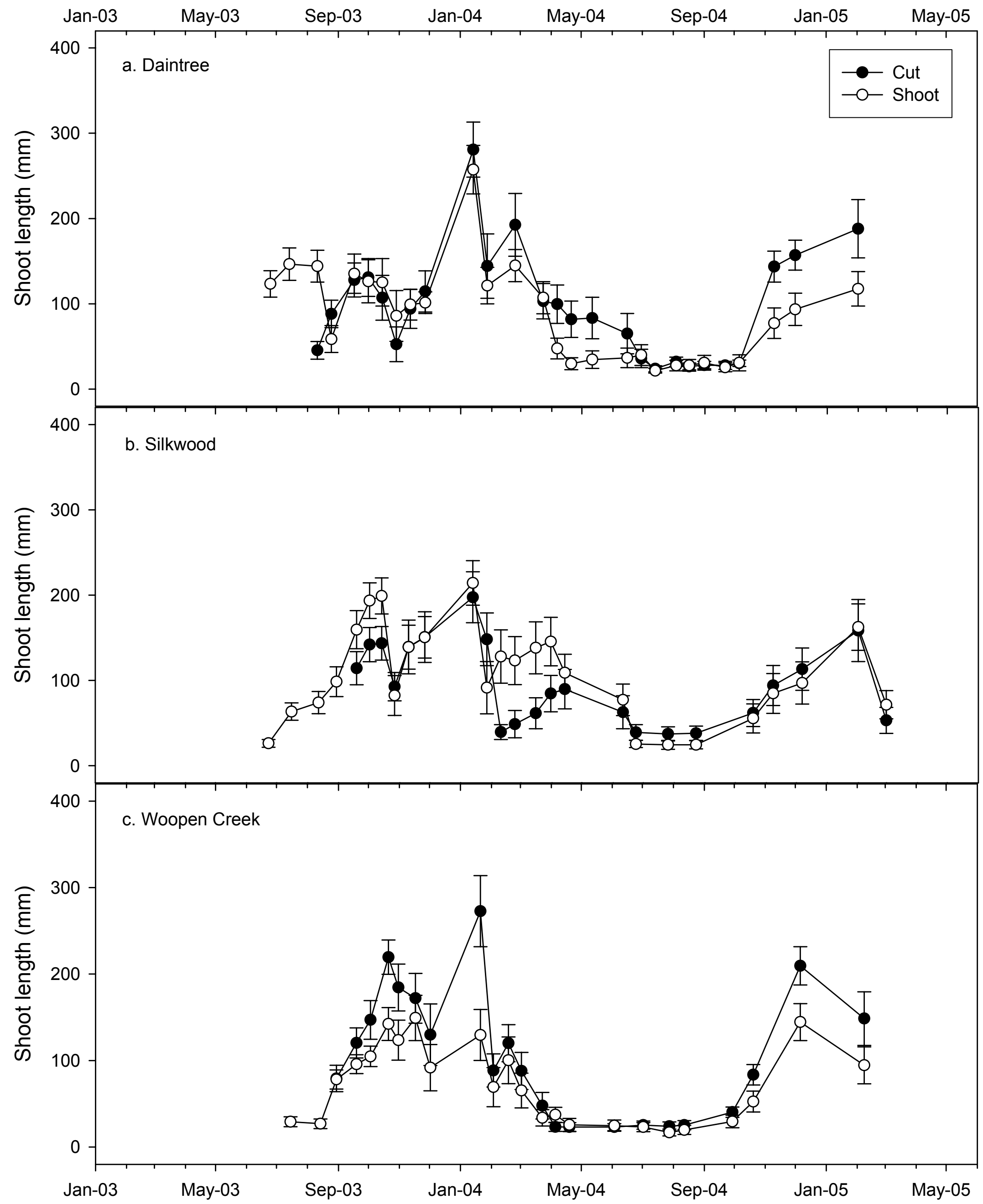


Figure 13.6. Mean shoot length for tagged pruned stems and non pruned shoots following pruning in June 2003. The vertical bars represent the standard error.

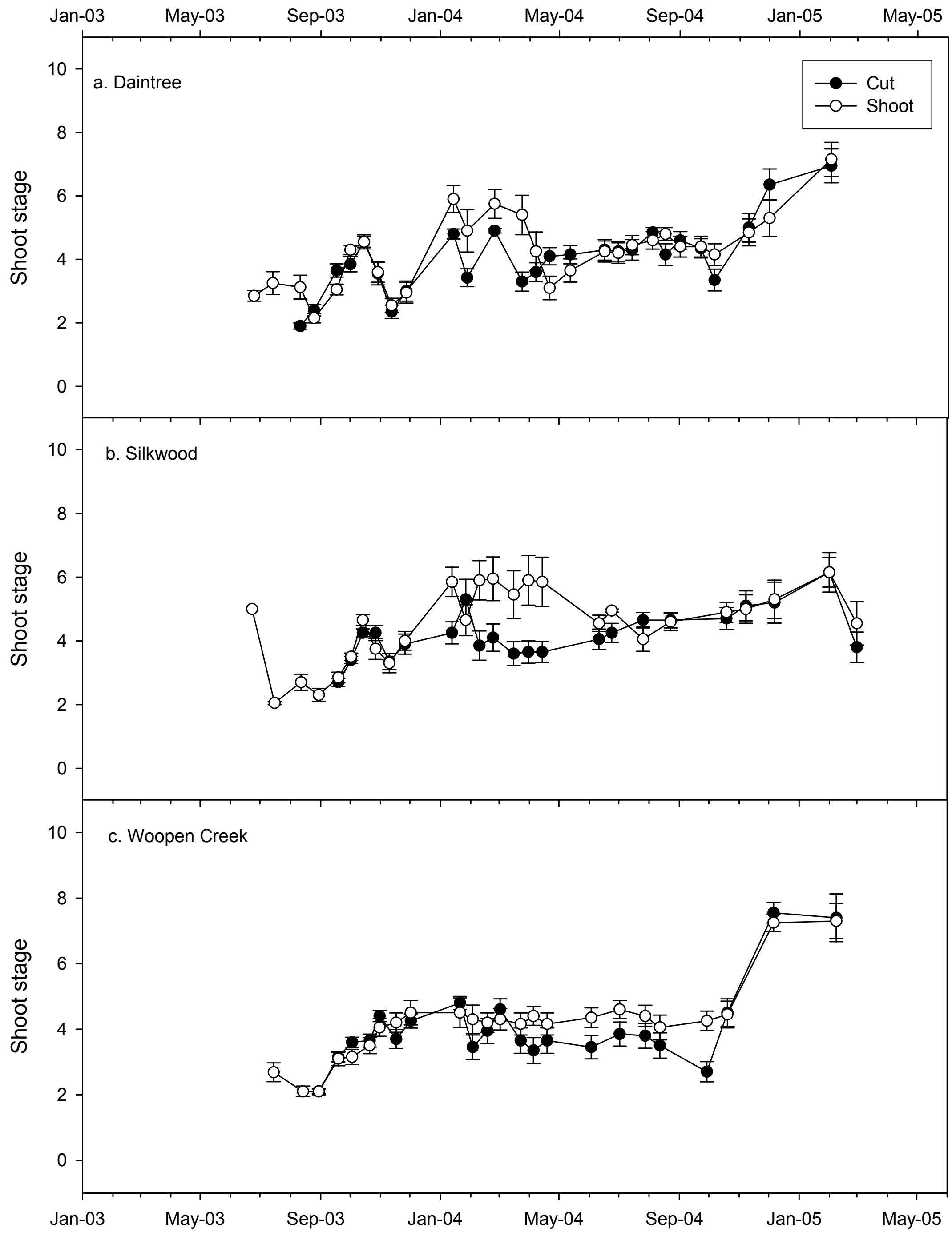


Figure 13.7. Mean shoot phenology stage for tagged pruned stems and non pruned shoots following pruning in June 2003. The vertical bars represent the standard error.

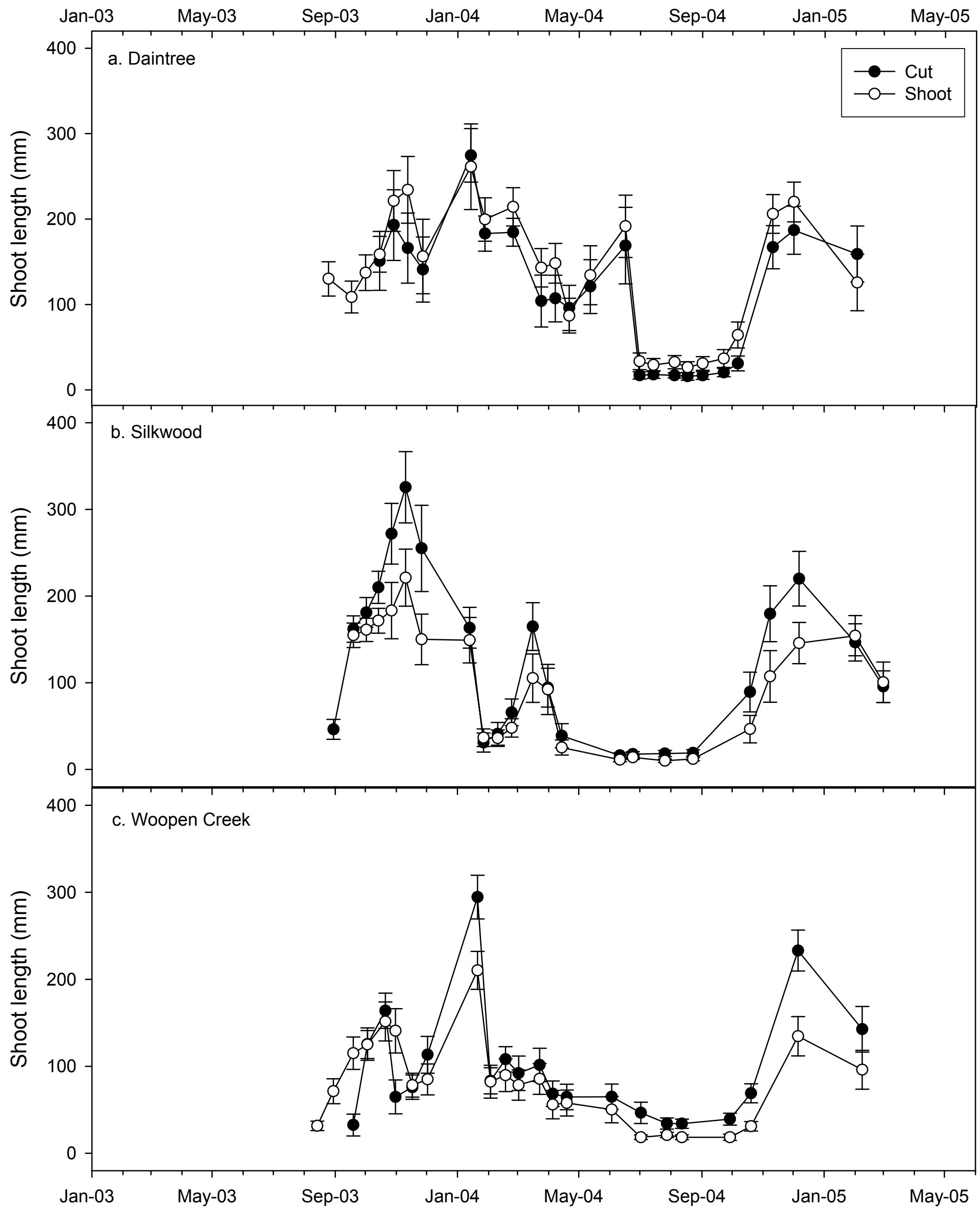


Figure 13.8. Mean shoot length for tagged pruned stems and non pruned shoots following pruning in August 2003. The vertical bars represent the standard error.

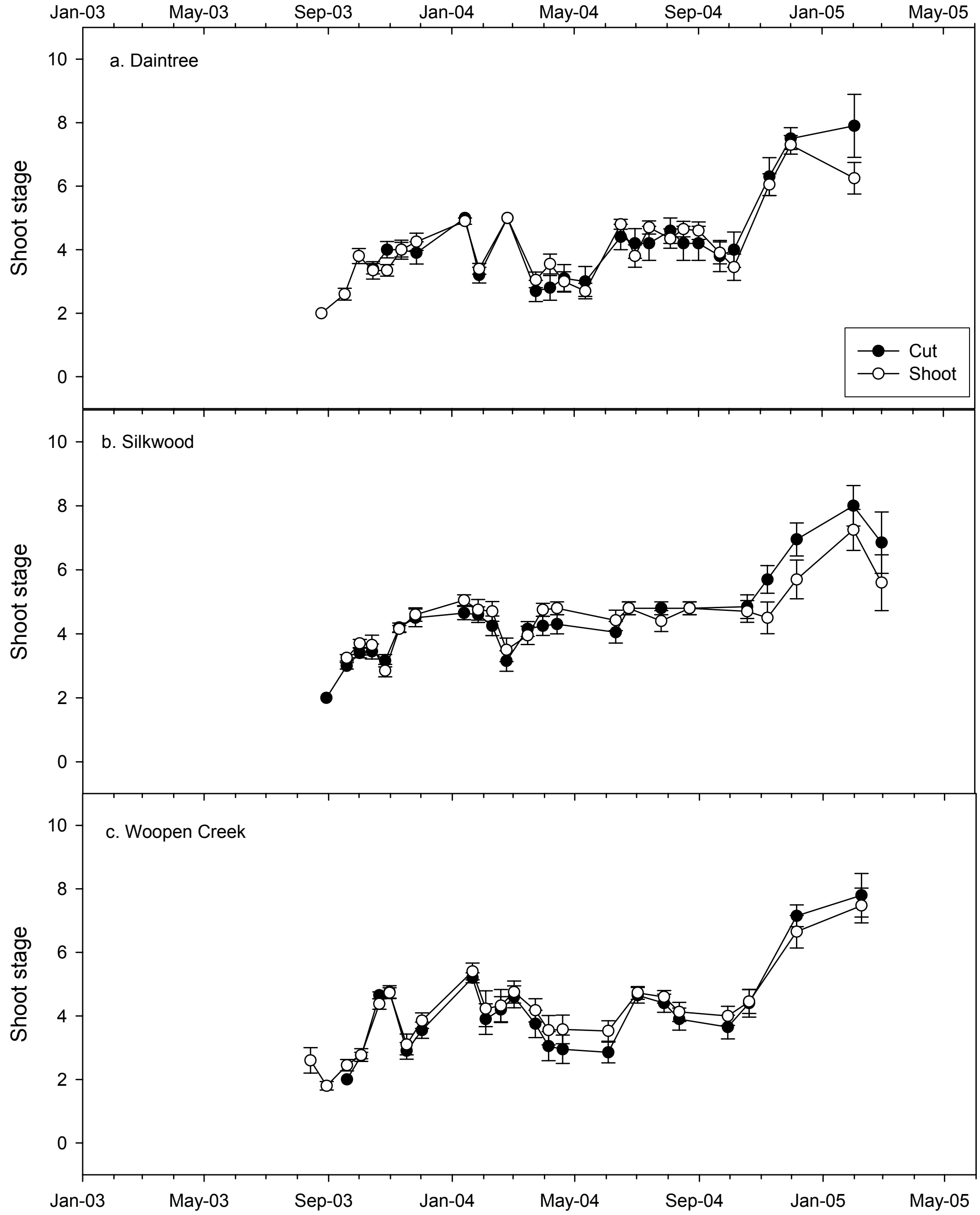


Figure 13.9. Mean shoot phenology stage for tagged pruned stems and non pruned shoots following pruning in August 2003. The vertical bars represent the standard error.

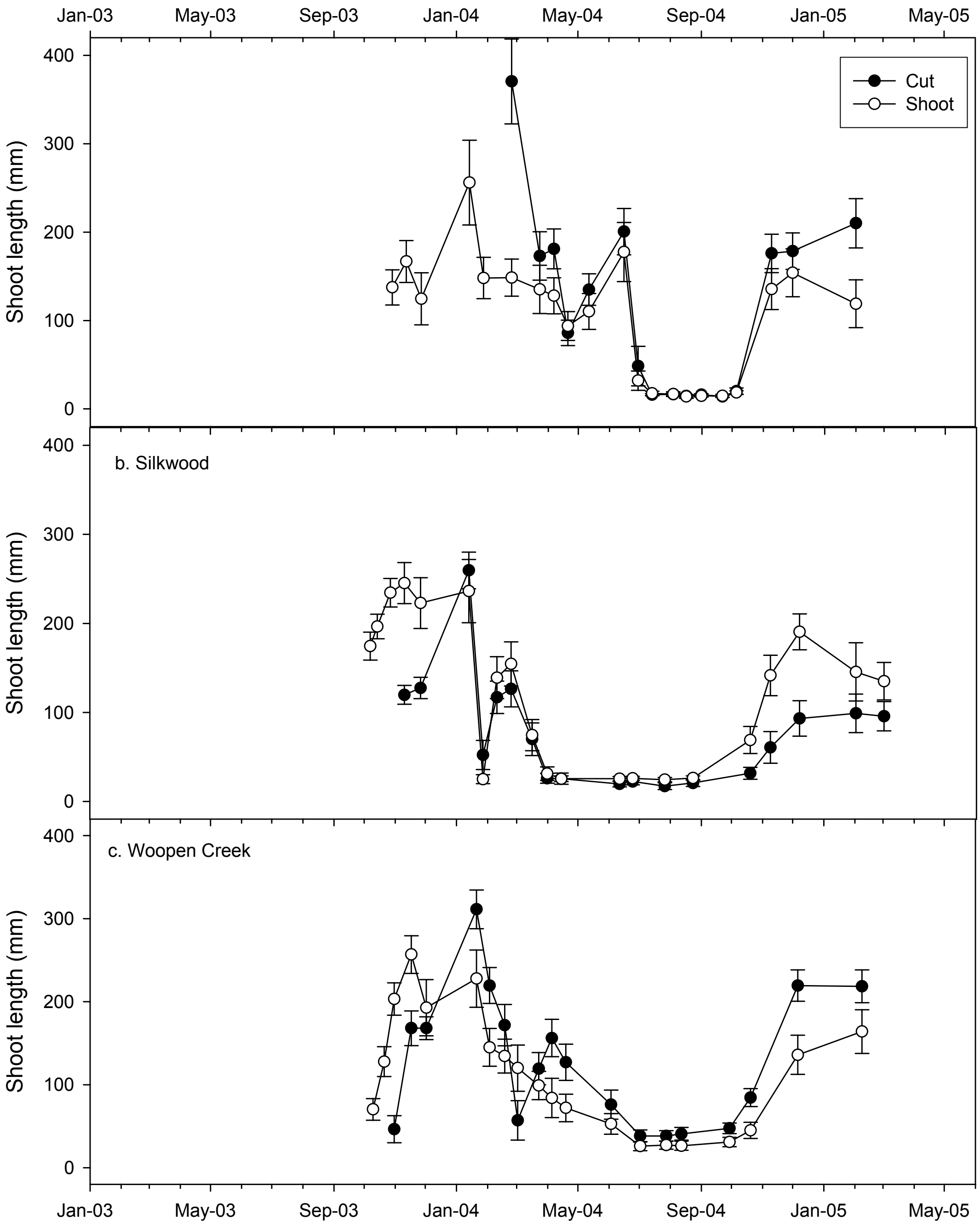


Figure 13.10. Mean shoot length for tagged pruned stems and non pruned shoots following pruning in October 2003. The vertical bars represent the standard error.

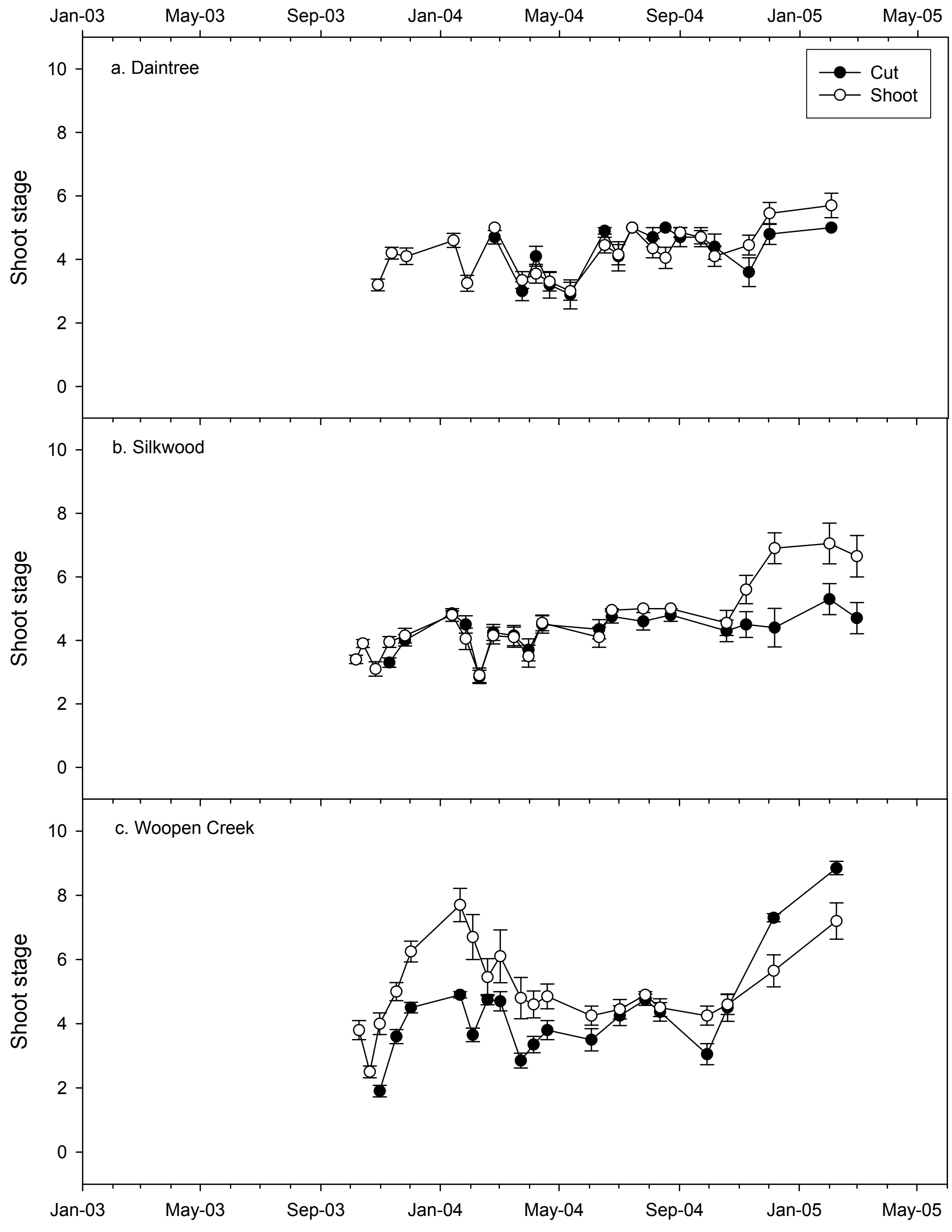


Figure 13.11. Mean shoot phenology stage for tagged pruned stems and non pruned shoots following pruning in October 2003. The vertical bars represent the standard error.

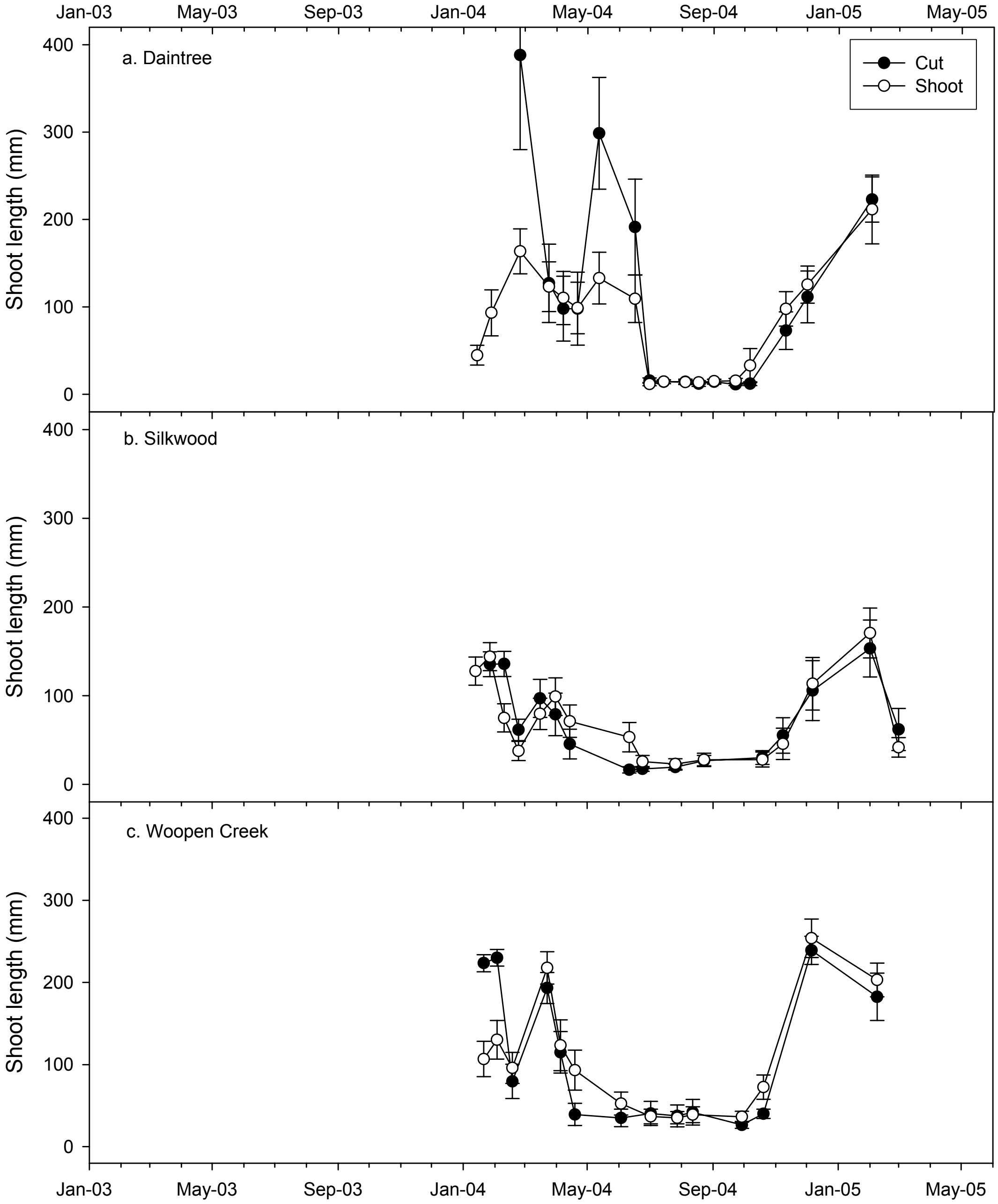


Figure 13.12. Mean shoot length for tagged pruned stems and non pruned shoots following pruning in December 2003. The vertical bars represent the standard error.

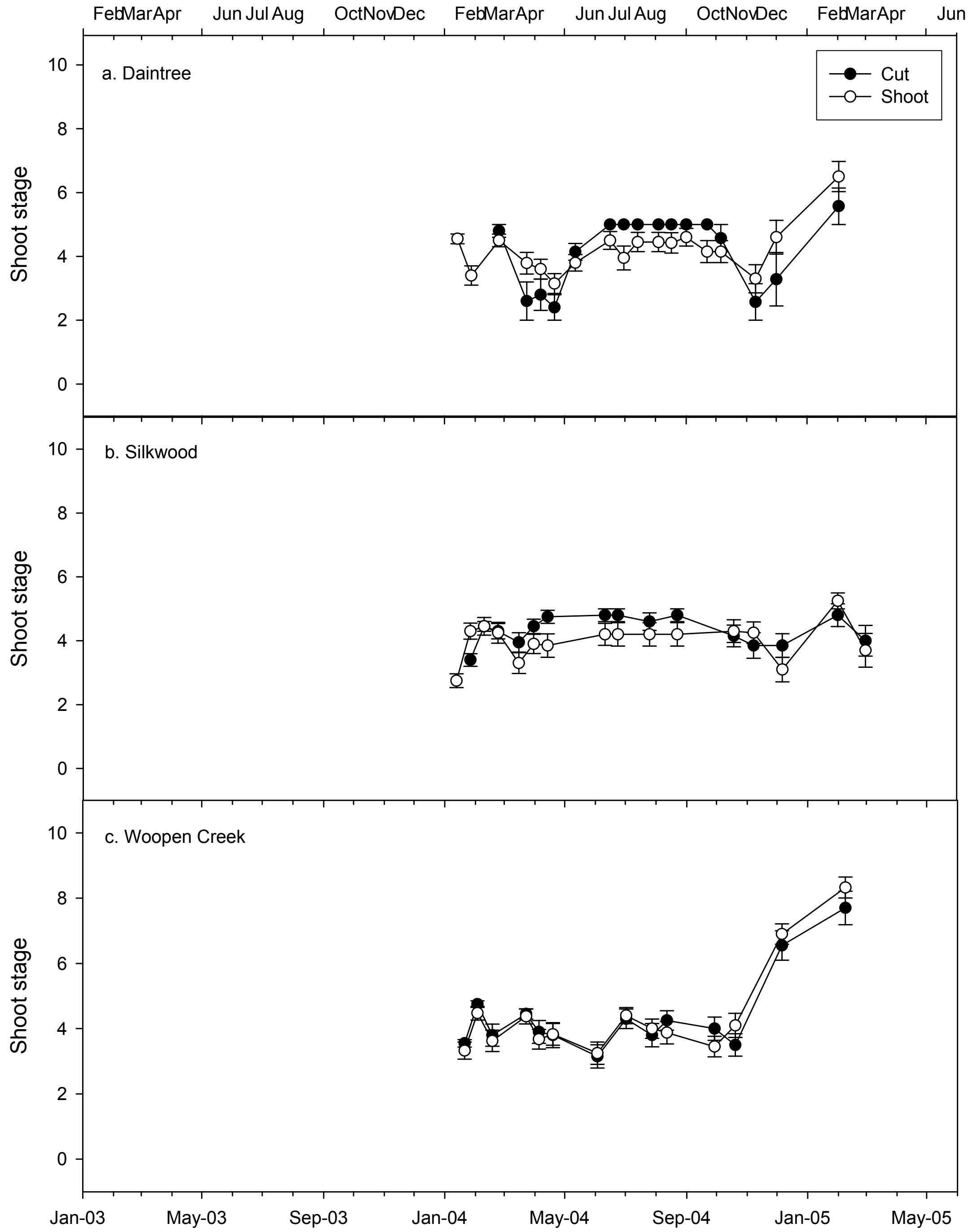


Figure 13.13. Mean shoot phenology stage for tagged pruned stems and non pruned shoots following pruning in December 2003. The vertical bars represent the standard error.

14.4 Discussion

Tree phenology

Pruning date influenced the number of flushes produced over the monitoring period from an average of five for the earliest date to an average of two flushes for the latest pruning date. Trees responded to pruning by producing a rapid succession of new shorts and flushes as soon as possible after pruning with a noticeable delay where pruning occurred in autumn (April) and during winter (June). In essence most of the growth only occurred during the warmer weather as predicted by glass studies conducted by (Diczbalis and Menzel, (1998). There is a long period from May 2004 to October 2004 in which little to no vegetative growth occurred regardless of the previous pruning date once again reinforcing the understanding that little vegetative activity occurs during the cooler months. All 2003 imposed pruning dates resulted in trees flowering and fruiting in the 2004/2005 season despite the difference in flush number (2 -5) produced following pruning. Panicle emergence in 2004 was preceded by a long dormant period which is believed to be conducive to improved flowering in a number of terminal flowering species (Davenport and Núñez-Elisea. 1997, Davenport 2000, Zheng *et al*., 2001) whereas there was little if any dormant activity leading up to the 2003/2004 flowering season.

Yield

Yield in the first season following all pruning treatments was low relative to the yield recorded in the second season. The earliest pruning date (February) was the only treatment which resulted in a harvestable yield being recorded (≈10-20 kg/tree) in the season following pruning. Where as in the second season following pruning mean yield was generally in excess of 20 kg/tree particularly for the first three pruning dates (February, April and June). There were some obvious site differences in yield performance in the second season with trees at Daintree returning the highest yields (in excess of 20 kg/tree) for the February, April and June pruning with the mean yield in later pruning dates (August, October and December) being below 20 kg/tree. This trend was not evident at sites north and south of Innisfail (Woopen Creek and Silkwood) where yields were similar (20-30 kg/tree) for most pruning dates, the exception being December where mean yields were generally below 20 kg/tree. This data suggests that heavily pruned trees need 12 months or more to recover prior to harvestable yields being recorded. Ideally 16 months or more is required with 21 to 25 months being necessary for the highest yields to occur. Interestingly the pruning dates did not markedly shift the harvest dates at any of the locations, suggesting that the flowering and harvest window is relatively fixed.

The February pruning date is only of practical consequence to rambutan producers in the more northern growing areas (Daintree to Cooktown) where harvest is near completion by the end of February. Whereas, in growing areas south of Cairns harvesting does not generally commence until February and can extend through to the end of April. The data suggests that heavy pruning should ideally occur as soon after harvest as possible, particularly for the northern growing areas.

Results obtained in this study are dissimilar to those obtained by researchers in the Northern Territory (Diczbalis and Wicks in Menzel *et al*., 1999) showed that structural pruning carried out in February resulted in 24% lower yields than control or non pruned trees. In the NT environment there is enough heat to ‘drive” the production of flush development following pruning with 3 to 4 flushes of growth produced after pruning and prior to panicle emergence in July to August. Whereas, in north Queensland temperatures are on the decline following the completion of harvesting in April/May and as a consequence little if any new growth following pruning is experience until September when mean temperatures begin to rise.

Pruning management
This raises the very practical issue of how often to conduct heavy pruning. Heavy pruning is required to keep trees to an economic picking height as well as to allow the ease of application of netting to protect the crop from winged vertebrate pests. In a mature orchard heavy pruning will have a severe impact on production potential in the following season. In conventionally managed orchards the bulk of the trees undergo heavy pruning in the same year resulting in no or at best low yields in the following season. This asynchronous production pattern is further exacerbated when seasonal conditions result in poor flowering or fruit set. Given the extended post pruning recovery time required for trees to start bearing again growers should consider implementing the following pruning management strategy.
Growers could consider splitting their rambutan areas into four with heavy pruning carried out on a block of trees every four year. In the alternative years trees are either not pruned or lightly pruned. This form of management ensures that half of the orchard is in a state of growth that allows for full flowering and fruit-set to occur (Table 13.5).

Table 13.5. Pruning management scenario which allows flowering and fruiting to occur on a yearly basis.

Block 1	Block 2	Block 3	Block 4
Year 1. Prune (heavy) following harvest	Year 4. Normal yields should occur. Light prune only following harvest.	Year 3. Normal yields should occur. Light prune only following harvest.	Year 2. Minor harvest may be expected. Prune only fruiting panicles at harvest.
Year 2. Minor harvest may be expected. Prune only fruiting panicles at harvest.	Year 1. Prune (heavy) following harvest	Year 4. Normal yields should occur. Light prune only following harvest.	Year 3. Normal yields should occur. Light prune only following harvest.
Year 3. Normal yields should occur. Light prune only following harvest.	Year 2. Minor harvest may be expected. Prune only fruiting panicles at harvest.	Year 1. Prune (heavy) following harvest	Year 4. Normal yields should occur. Light prune only following harvest.
Year 4. Normal yields should occur. Light prune only following harvest.	Year 3. Normal yields should occur. Light prune only following harvest.	Year 2. Minor harvest may be expected. Prune only fruiting panicles at harvest.	Year 1. Prune (heavy) following harvest

The inability of rambutan trees, grown in north Queensland, to fully recover from heavy pruning and fruit within 12 months suggests that other techniques need to be investigated to control vegetative growth and enhance flowering. With this in mind experiments were conducted to examine the effects of regulating vegetative growth by both physical (root pruning and cincturing) and chemical means (anti gibberellins and salts of potassium phosphate).

15. Effect of Pre-flowering chemical and physical growth regulation on shoot development

15.1 Introduction

Young rambutan trees grow vigorously, particularly when conditions are warm and humid (Diczbalis and Menzel 1997). Rapid vegetative growth is antagonistic to reproductive growth. The aim of this work was to trial a range of chemical and physical growth regulators on their ability to stop vegetative growth and hence promote flowering. The treatments imposed fell into three categories;

- Growth regulators (paclobutrazol. uniconazol and prohexidione calcium). Paclobutrazol and uniconazol are both triazoles that have strong antigibberellin properties and are relatively old growth regulator chemicals used commercially in mango and avocado production. Prohexidione calcium is a relatively new compound that inhibits the synthesis of gibberellins and is currently registered for growth control in Apples in the USA. The above chemicals were applied as foliar sprays.
- Foliar phosphorous and potassium (MKP; monopotasium phosphate). This treatment is based on management practices from SE Asia where high P and K prior to flowering are believed to benefit flower initiation. There are also claims that it hardens new flush rapidly and may prevent unwanted preflowering flushes (Hoger 2000).
- Physical (cincturing). This treatment is a common management technique in lychee where physical damage to the phloem is used to control unwanted flush development and can improve flowering.

15.2 Application on young trees

Materials and Method

Treatments application commenced from late October 2003 on young three year old (variety R134) vigorously growing trees with the aim of stopping flushing and enhancing flowering. The treatments, Table 14.1, were imposed on 30 trees as a completely randomised design with six treatments and five replicate blocks. Following treatment application, whole tree shoot development was visually assessed and recorded over a four month period. Trees were rated for the percentage of new, hardening, mature flush and panicle emergence on seven occasions post treatment application. A tree shoot development rating was conducted five days prior to the application of treatments.

The three growth regulator foliar spray treatments were imposed at the start of the trial (27 Oct 2003) and again four weeks later on 25 November 2003. The MKP foliar sprays were applied approximately fortnightly on 5 occasions from the 27 October 2003 to the 24 December 2003. All foliar treatments were applied using a hand held spray lance until runoff.

The cincturing treatment was applied on the 11 November 2003 using a thin knife blade (Stanley Knife®, 0.2 mm). The cincture was applied to the main trunk approximately 50 cm above ground level. Plate 14.1 shows the size and type of cincture applied. The photograph was taken on the 3 December 3 weeks after application.

Table 14.1. Treatments imposed on young rambutan trees

Treatment	Rate of Product	Application Timing
1. Untreated Control	N/A	N/A
2. Paclobutrazol (Cultar®)	0.2 %	0 and 4 wks
3. Uniconazol (Sunny®)	0.05 %	0 and 4 wks
4. MKP	1.0 %	Fortnightly to flower
5. Cincture (Fig 2)	Knife blade cut	Once at first spray
6. Prohexidione calcium (Apogee®)	1.0 g/4.0 L (0.025%)	0 and 4 wks

Plate 14.1. Knife blade cincture wound at 3 weeks after application. Note bark lifting at the edge of the wound surface.

15.3 Results

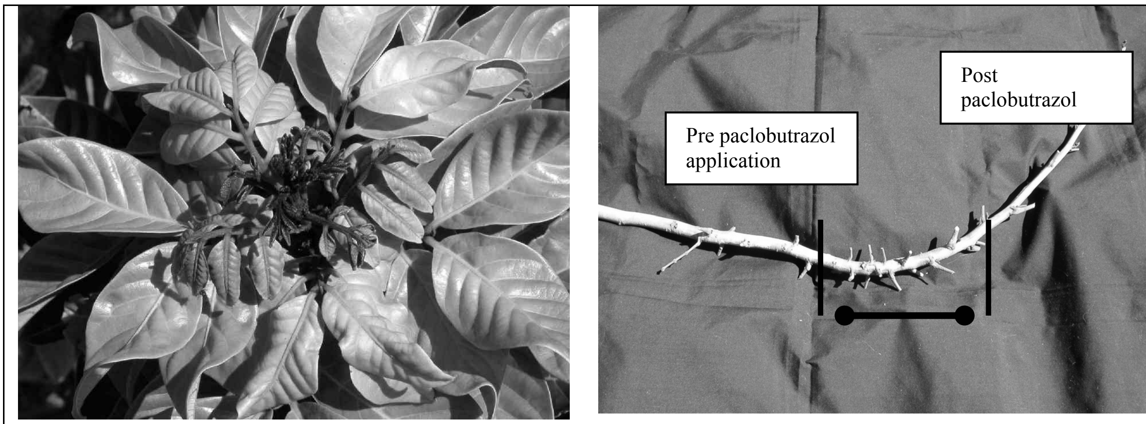
Whole tree flushing summaries are presented in Figure 14.1 and show the high variability which occurred in tree activity during the four month observation period. No treatment resulted in panicle emergence and subsequent flowering. Trees under all treatments were actively flushing prior to treatment application through to the end of February, with the least activity occurring from late December through to early February.

No treatment, including cincturing managed to stop flushing from occuring. Table 14.2 shows the mean average mature flush percentage over the observation period and the highest mean mature flush rating and the date that it was observed. The highest mean mature flush rating (43%) over the observation period occurred on Uniconazol treated trees where as the lowest rating (26%) occurred in paclobutrazol treated trees. The highest mature flush rating (89%) at a given observation period occurred in untreated control trees where as the lowest individual rating occurred for Prohexidione calcium treated trees.

Two treatments did affect subsequent shoot development. These included paclobutrazol and cincturing. The subsequent flush following application of paclobutrazol was clearly compacted with short internodes (Plate 14.2a). However the flush following the compacted flush was again normal (Plate 14.2b). The flush following cincturing was pale in colour, as though iron deficient (Plate 14.3a) relative to normal flush from control treated plants (Plate 14.3b). Subsequent development of the flush was not affected.

Table 14.2. Mean mature flush rating over the observation period and the highest mean mature flush rating for young rambutan trees treated with chemical and physical growth regulation treatments.

Treatment	Mean mature flush rating over the observation period	Highest mean mature flush rating and the date observed
1. Untreated Control	29%	89% (20 Jan 04)
2. Paclobutrazol (Cultar®)	26%	70% (9 Feb 04)
3. Uniconazol (Sunny®)	43%	78% (22 Jan 04)
4. MKP	33%	71% (24 Dec03)
5. Cincture (Fig 2)	36%	80% (20 Feb 04)
6. Prohexidione calcium (Apogee®)	30%	59% (25 Nov 03)



a. b.

Plate 14.2.
a). Post paclobutrazol applied flush showing compacted growth.
b). A deleafed paclobutrazol treated shoot showing normal growth prior to paclobutrazol application followed by compacted growth (underlined) immediately post paclobutrazol application and the return to normal growth on the second flush post paclobutrazol application.

a. b.

Plate 14.3.
a). Pale flush following the application of a cincture compared to
b.) flush from control treated trees.

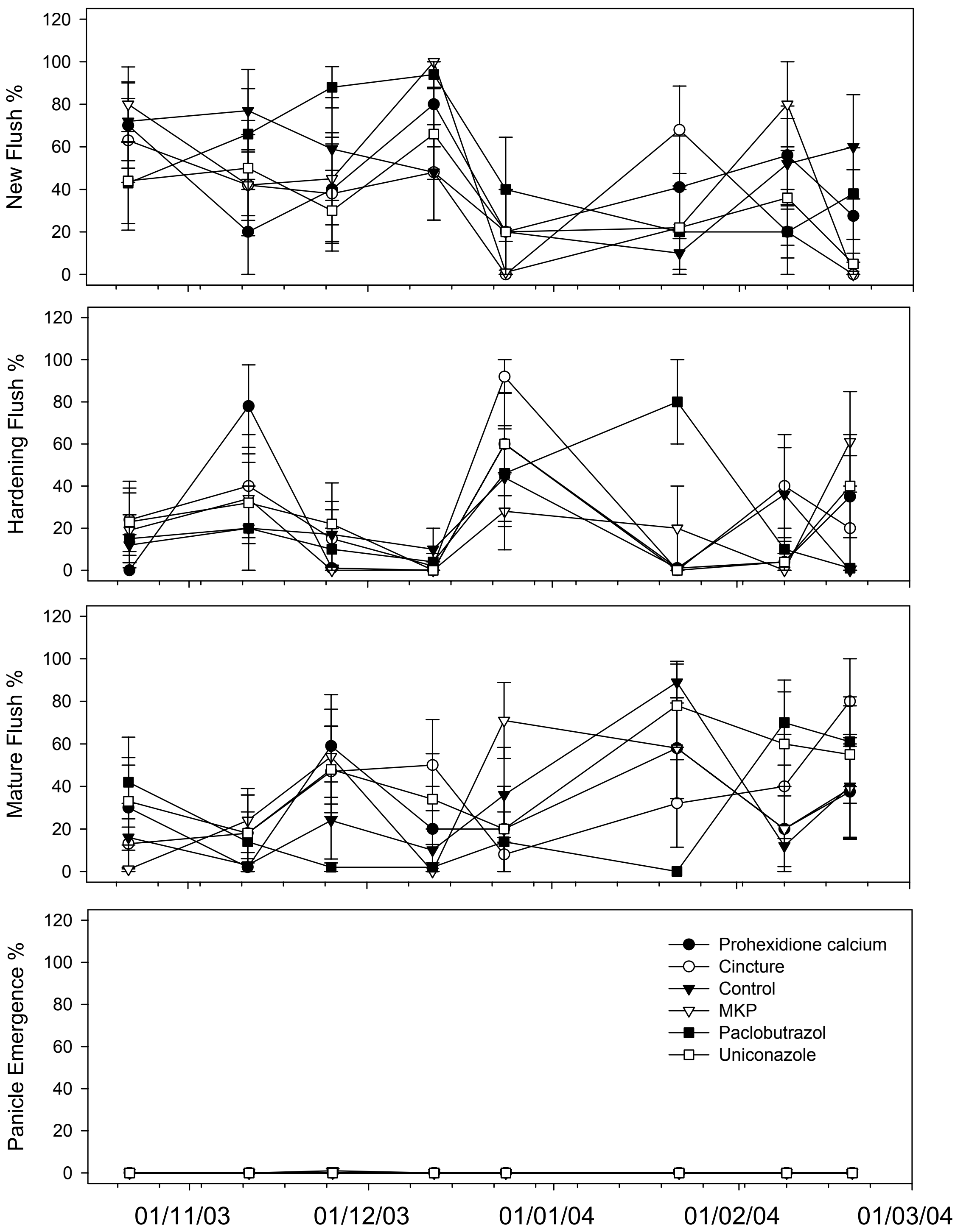


Figure 14.1. Mean whole tree shoot phenology ratings with the percentage of the tree rated for new, hardening, mature flush and panicle emergence on young rambutan trees treated with chemical and physical growth regulation treatments. The vertical bars represent standard errors (SE).

15.4 Application on mature cropping trees

Materials and Methods

Treatments application commenced from early November 2003 on mature 12 year old (*cv.* R134) vigorously growing trees with the aim of stopping flushing and enhancing flowering. The treatments, Table 14.2, were imposed on 24 trees using a randomised complete block design with six treatments and four replicate blocks. Following treatment application whole tree shoot development was visually assessed and recorded over a four month period. Trees were rated for the percentage of new, hardening, mature flush and panicle emergence on seven occasions post treatment application. A tree shoot development rating was conducted five days prior to the application of treatments.

The three growth regulator foliar spray treatments were imposed at the start of the trial (11 November 2003) and again four weeks later on 9 December 2003. The MKP foliar sprays were applied approximately fortnightly on 4 occasions from the 11 November 2003, with the last application occurring on the 24 December 2003. All foliar treatments were applied using a hand held spray lance. Trees were sprayed until runoff (≈4.0 L/tree). The cincturing treatment was applied on the 11 November 2003 using a pruning saw blade (1.5 mm width). The cincture was applied to the main branches.

Table 14.2. Treatments imposed on mature rambutan trees.

Treatment	Rate of Product	Application Timing
1. Untreated Control	N/A	N/A
2. Paclobutrazol (Cultar®)	0.2 %	0 and 4 wks
3. Uniconazol (Sunny®)	0.05 %	0 and 4 wks
4. MKP	1.0 %	Fortnightly to flower
5. Cincture (Fig 2)	Knife blade cut	Once at first spray
6. Prohexidione calcium (Apogee®)	1.0 g/4.0 L (0.025%)	0 and 4 wks

Results and Discussion

The chemical growth regulator and physical growth reduction treatments tested were not effective in stopping flushing and or inducing flowering in young three year old marcotts whereas in mature trees the data suggests that foliar applications of MKP or Uniconazol resulted in significantly higher panicle emergence than in control or the other treatments (Paclobutrazol, cincturing and prohexidione calcium). In mature trees the peak mature flush ratings were similar for all treatments but only the MKP and Uniconazol treatments resulted in significantly improved flowering (Table 14.3).

In young trees the use of paclobutrazol showed signs of altering flush growth by compacting the flush which emerged following application. The compaction was substantial on the flush which occurred after the two applications of paclobutrazol. The subsequent flush, however, was not affected with the second flush following application returning to normal. This effect was not as evident on mature treated trees.

The lack of effect of the paclobutrazol treatment in flower induction is surprising given the positive reports of the treatments in Thailand (Muchjajib, 1998) and Indonesia (Prawitasari and Sri Wahyuni, 2005). Muchjajib (1998) reported that paclobutrazol was the best chemical, compared to ethephon and SADH, to induce early and high flowering. The number of flowers per panicle was high and the shorter panicles produced resulted in good pollination. Application rates of 1.5, 3.0 and 4.5 mM all produced high flowering relative to control but the 3.0 mM rate was considered to give the best combination of early flowering and harvest date and yield.

Foliar paclobutrazol and uniconazol will be re-tested post pruning to see if they can reduce the amount and size of regrowth relative to untreated trees.

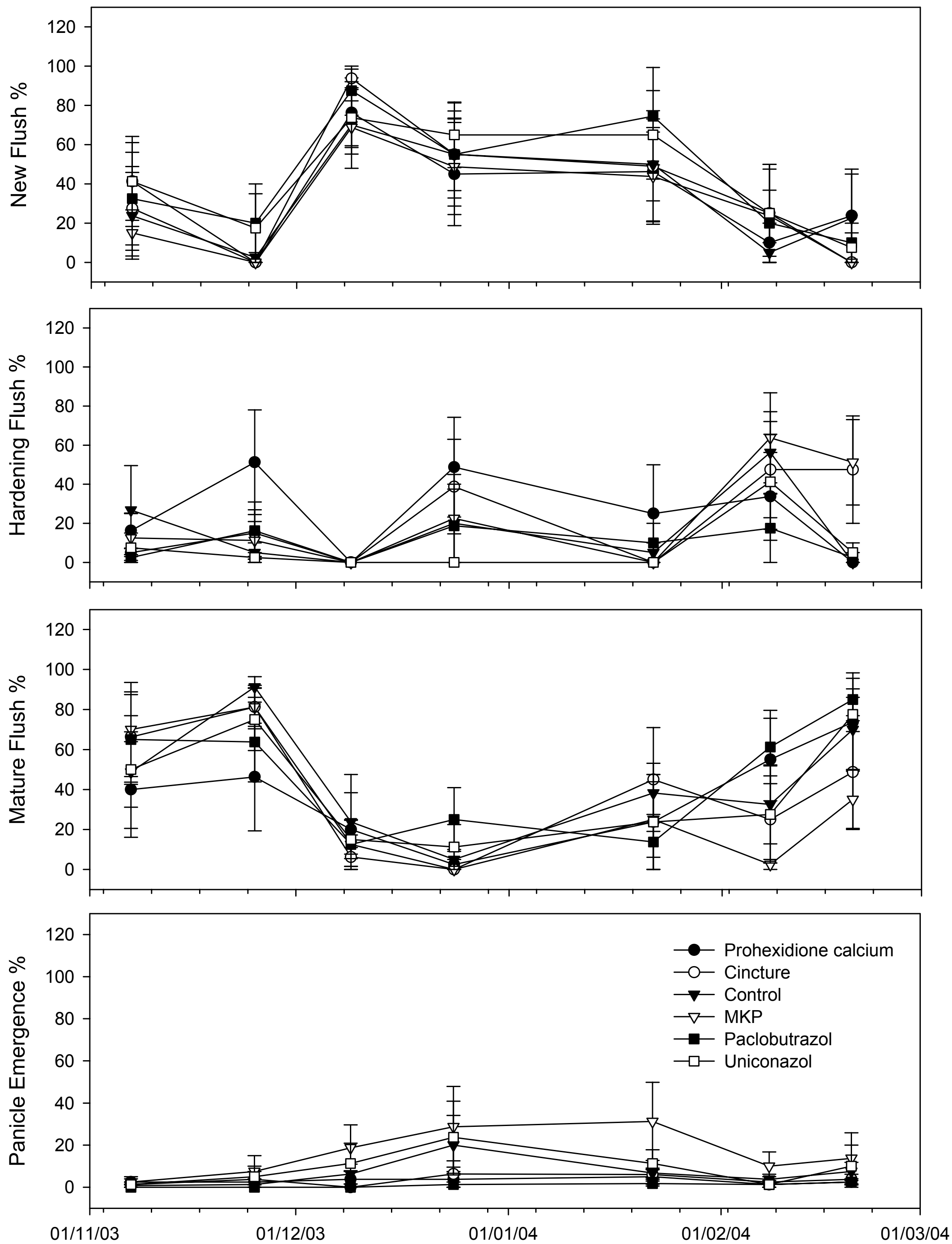


Figure 14.2. Mean whole tree shoot phenology ratings with the percentage of the tree rated for new, hardening, mature flush and panicle emergence on mature rambutan trees treated with chemical and physical growth regulation treatments. The vertical bars represent standard errors (SE).

Table 14.3. Mature flush ratings and panicle emergence rating for mature rambutan trees treated with chemical and physical growth regulation treatments.

Treatment	Mean mature flush rating over the observation period	Peak mature flush rating and the date observed	Highest mean Panicle emergence rating and date observed
1. Untreated Control	44%	91% (25 Nov 03)	6.8 (22 Jan 04)
2. Paclobutrazol (Cultar®)	47%	85% (20 Feb 04)	1.8 (22 Jan 04)
3. Uniconazol (Sunny®)	40%	78% (20 Feb 04)	23.8 (24 Dec 03)
4. MKP	32%	81% (25 Nov 03)	28.8 (24 Dec 03)
5. Cincture (Fig 2)	39%	81% (25 Nov 03)	6.3 (24 Dec 03)
6. Prohexidione calcium (Apogee®)	37%	74% (20 Feb 04)	3.8 (9 & 24 Dec 03)

16. Effect of Pre-flowering chemical and physical growth regulation on shoot development in rambutan – Trial 2.

16.1 Introduction

In trial one the application of a range of anti-gibberellins and cincturing had a minimal effect on flush development and type. There was some indication that foliar applied paclobutrazol resulted in compacted shoot growth in the flush following application, however none of the treatments was able to stop flushing or significantly increase the percentage of flowering flush (panicle emergence).

The aim of this trial was to concentrate the trial efforts on the use of paclobutrazol and uniconazol, two readily available growth regulators used commonly in mango and avocado crops for controlling vegetative vigour and enhancing flowering (Winston, 1992, Sao Jose and Reboucas, 2000, Mena *et al*. 2003) and compare their performance against a physical growth control method – cincturing.

16.2 Materials and Methods

The orchard block selected for the trial was harvested in March 2004 and pruned in early April 2004. The trees flushed almost immediately following pruning. Four treatments (control, 1.5 ml/L Cultar® (250 g/L as paclobutrazol), 1.0 mL/L Sunny® (950g/L uniconazol) and cincturing (1.5 mm cut) were applied to high density 4 year old rambutans (cv. Jitlee). The trial design was a randomised complete block with 4 replicate blocks. Each block consisted of 5 replicate trees per treatment. Five tagged shoots were monitored and measured per tree. For each treatment a total of 100 replicate shoots were monitored and measured (4 blocks x 5 trees x 5 shoots).

The chemical growth regulators were applied as foliar spray treatments on five occasions at approximately monthly intervals during 2004 following development of the first flush after pruning. The cincturing treatment was applied following maturity of the second flush (14 September). The foliar sprays were applied with a commercial mist blast sprayer and a spray volume of 1.3 L was applied per tree. The sprays were made up following label recommendations and included a adjuvant (Agral 0.5 mL/L). At the spray rate above the chemical application rate was 1.95 ml of paclobutrazol and 1.3 ml of uniconazol per tree.

Treatment trees were tagged in early May and the first foliar spray applied to trees in mid flush (19 May). The cincturing treatment was applied on the 14 Sept 2004 following maturity of the second flush. Shoot phenology and length were recorded from 27 May to 29 November September. The bulk of measurements occurred on a monthly interval with fortnightly measurements occurring from 30 September to 1 November. All means were compared using standard error calculations

16.3 Results

Flush stage

At each monitoring occasion the tagged flushes were rated for flush stage. Vegetative growth was categorised as either new, hardening or mature flush whereas reproductive growth was categorised as either flowering flush or panicle (Plate 15.1). Trees in all treatments continued to flush through to early October with the new flush rating varying from approximately 40% to 80% during the monitoring period. Early signs of flowering flush (panicle emergence) were recorded at the end of September. Active flowering flush occurred from mid October to early November with 34 to 56 % of tagged panicles in panicle emergence mode. At the last measurement date (29 November 2004) the percentage of shoots which were showing reproductive activity (panicle emergence or panicle development) was 57%, 53%, 39% and 34% for the treatments control, paclobutrazol, cincturing and uniconazol respectively. Figure 15.1 indicates there was little if any significant difference between treatments for flush activity with a similar rate of conversion of vegetative shoots to flowers for all treatments.

Flush length
Flush length along with flush stage of each of the tagged shoots was measured from the start of chemical treatment applications. This measurement was conducted to determine if the chemical growth regulator treatments had had any effect on flush development relative to the control treatment. Flush length of cinctured trees was not measured until after the application of cincture on 14 Sep 2004. Figure 15.2 shows the average flush length for the five phonological stages monitored.

There were no significant differences in flush length for the three vegetative stages between the control and flush control treatments. No compaction of new flush was observed as in trial one. Length of reproductive growth, flowering flush or panicle, did differ depending on treatment. The reproductive growth of control and uniconazol treated trees were significantly longer than paclobutrazol and cintured trees although the difference was small.

16.4 Discussion

The application of foliar anti gibberellins (paclobutrazol and uniconazol) and the physical growth control of cincturing failed to significantly alter flushing patterns and vegetative flush length over a six month period in young actively growing rambutan trees.

In avocado the recommended label rate for control of vegetative growth is 0.05% while the label concentration of paclobutrazol used as a foliar spray in apples varies from 0.05% to 0.1% with the lower rate recommended for use on less vigorous trees.

The failure of both of the anti-gibberellins foliar spray treatments to reduce flush length despite changes in concentration following trial one, is worthy of note. In trial one three foliar applications of paclobutrazol (250 g/L) at 0.2% resulted in compacted flush. In this trial five applications of paclobutrazol at 0.15% appeared to have no effect on vegetative growth and a marginal effect on the length of reproductive growth. In the case of uniconazol; three applications of 0.05% (50g/L) in trial one did not effect vegetative flush length, hence in this trial five applications of 0.1% concentration were utilised. Again there was no discernable effect on vegetative or reproductive shoot length relative to control trees. Neither chemical treatment enhanced the flowering status of trees relative to the control treatment.

The results in this trial are different from findings from other researchers (Muchjajib, 1998, Prawitasari and Wahyuni 2005). Muchjajib (1998) studied the effect of paclobutrazol at three concentrations (1.5, 3.0 and 4.5 mM equivalent to 0.44 g/L, 0.88 g/L and 1.32 g/L) applied as two foliar sprays 14 days apart during vegetative development on vegetative growth and reproductive outcome and yield. He reported that paclobutrazol significantly induced early flowering relative to control trees (10-12 days) but the flowering percentage and number of flowers per panicle were only marginally higher than in control trees.

	New Flush; seen emerging from a mature flush
	Hardening Flush; leaves are near fully developed but the tissue is still soft and chlorophyll is not full developed
	Mature flush; Leaves are fully developed and hardened with full chlorophyll development
	Flowering flush; the new flush is reproductive with florets formed on the emerging rachis
	Panicle; fully developed panicle with early flower opening leading to the start of anthesis.

Plate 15.1. Rambutan flush description categories used to describe tree phenology.

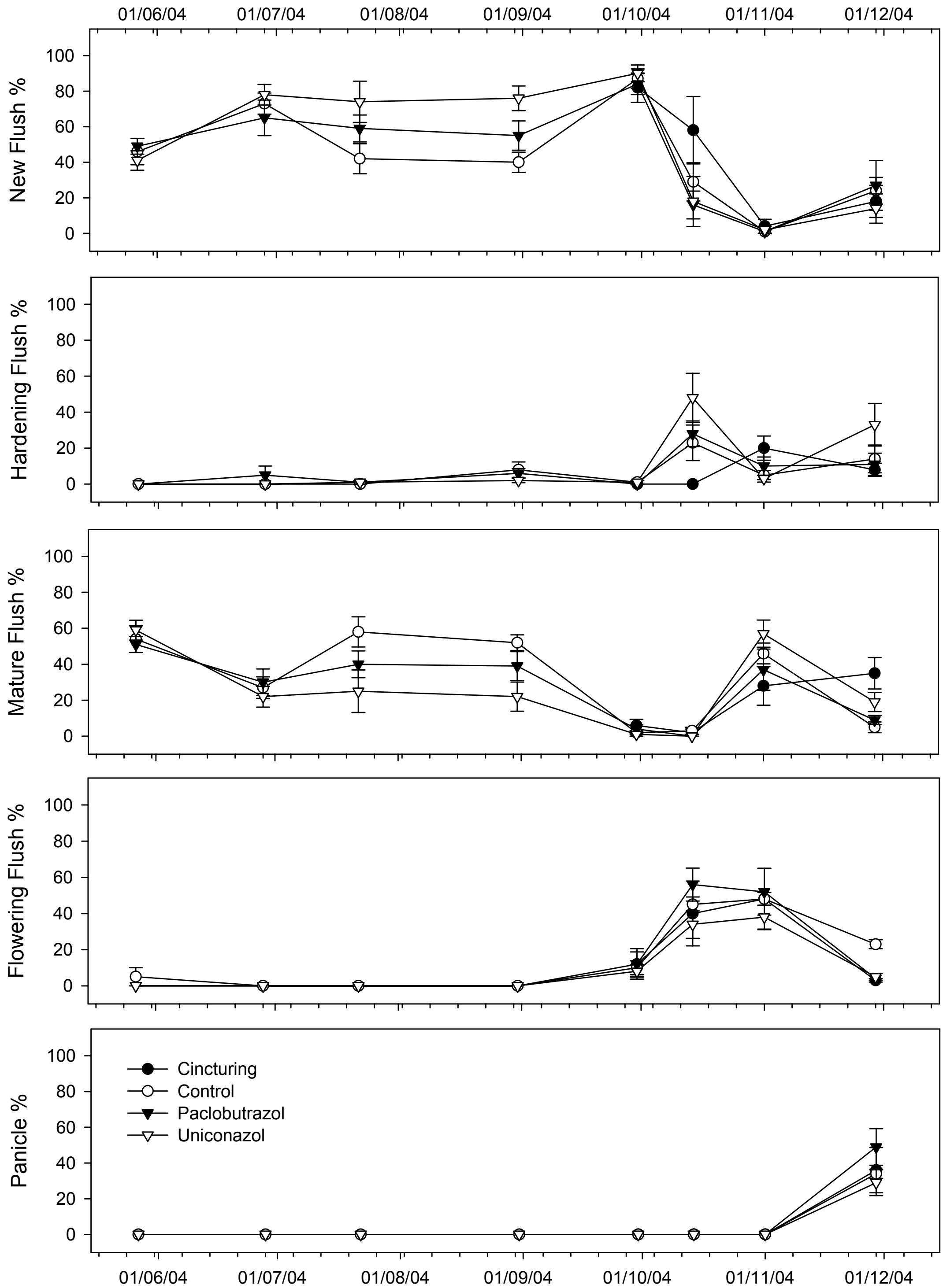


Figure 15.1. Rambutan shoot phenology (percentage new, hardening and mature vegetative flush, flowering flush and panicle) for control treatments and trees treated with paclobutrazol, uniconazol and cincturing).

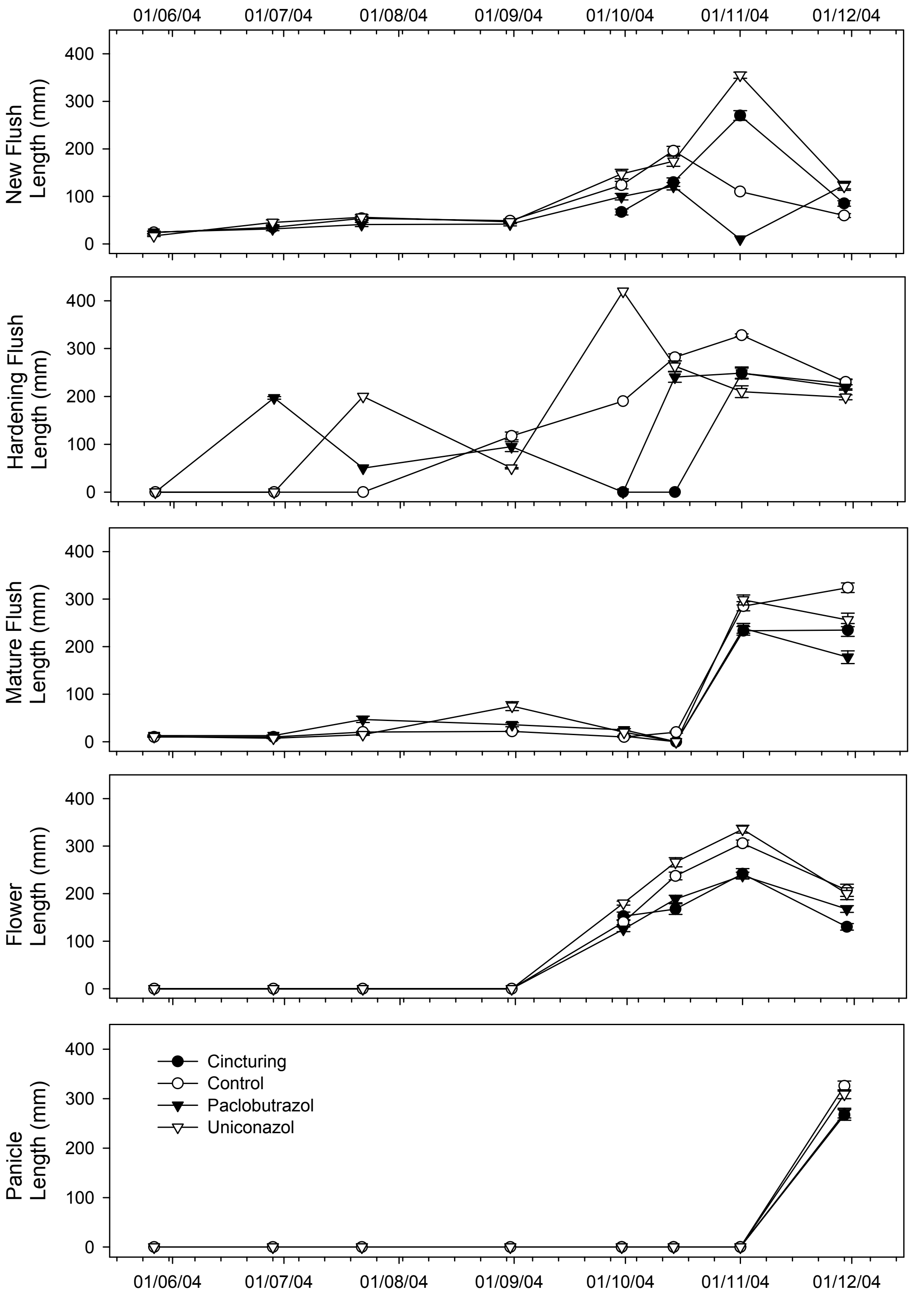


Figure 15.2. Average rambutan shoot length (mm) of new, hardening and mature vegetative flush, flowering flush and panicle for control treatments and trees treated with paclobutrazol, uniconazol and cincturing.

Yield of placlobutrazol treated trees was significantly higher than control trees for applications of 1.5 and 4.5 mM concentration but similar to control at 3.0 mM. The chief benefit from using paclobutrazol was reported to be due to the earliness of production which allowed growers to capitalise on higher prices. Prawitasari and Wahyuni (2005) report in a abstract that the application of 1.5 or 3.0 g/tree of paclobutrazol significantly increased the number of reproductive buds relative to control trees in a "off" or low flowering year. The method of application was not reported however both treatments resulted in reduced panicle length and increased the chlorophyll content of leaves below the panicle. They report that the optimum application rate of paclobutrazol is 1.5 g/tree however at the higher rate bud dormancy caused by paclobutrazol could be broken by a 2% foliar spray of potassium nitrate. The paclobutrazol rates used in this trial was 0.375g/L, slightly less than the lowest concentration used by Muchjajib (1998). This rate was chosen because at 0.5 g/L, application to small trees resulted in severe compaction of shoots (Chapter 12).

The plant growth regulator uniconazol has not had a significant effect on rambutan vegetative growth or reproductive development. There are no other available reports of the effects of uniconazol on rambutan. Uniconazol has been reported to effectively reduce shoot length and volume of canopy in Avocado (Mena *et al*., 2003) and Pecan (Graham and Storey, 2000) whereas Alina and Jakobczak (1998) report that Uniconazol had no effect when used as a growth retardant on plum trees.

In this trial, as in trial one, cincturing (girdling or ringing) also failed to influence vegetative growth or enhance reproductive development whereas Poerwanto and Irdiastuti (2005) reported that cincturing rambutans followed by a foliar spray of KNO_3 resulted in earlier flowering, more fruits per bunch and a higher percentage of starch in top growth.

This trial suggests there is insufficient evidence to recommend either the use of chemical growth regulators to control the vegetative growth and enhance flowering in young rambutan trees.

17. Effect of cincturing (girdling) and potassium nitrate foliar sprays on shoot development in mature rambutan.

17.1 Introduction

Cinctuing or girdling has long been used in Sapindacious crops such as lychee (Zang 1997) and longan (Charoensri *et al*. 2005) to stop late autumn flushing and enhance the prospects of flowering and subsequent fruit set. The use of cincturing in rambutan as a flush control and flower induction tool is rarely if ever mentioned in the literature. In Tindal's (1994) review on rambutan cultivation practices the technique is raised only in its role for propagating material by marcotting. In Indonesia cincturing has been trialled as a flush and flowering management tool. Poerwanto and Irdiastuti (2005) reported that in Indonesia cinctured rambutan trees flowered earlier and had more fruit per panicle than un-cinctured trees with cincturing increasing the starch content of the tree top relative to that of roots. The depth and width of the cincture wound was not described. The experiments also utilised a foliar application of KNO_3 40 days after cincturing, presumably as a bud breaking mechanism.

The key issue here is the use of cincturing, in "wet warm" years where growth cessation does not occur, to stop growth sufficiently long enough to allow flowering to occur on recommencement of growth. This trial was designed to test the validity of cincturing in combination with KNO_3 as a bud breaking tool as a technique for managing flowering in rambutan.

17.2 Materials and Methods

In August 2005, 48 sixteen year old trees of the *cv*. R134 were selected in a commercial orchard to trial the combination of cincturing and potassium nitrate sprays on floral induction. The trial was designed as a randomised complete block with 6 treatments replicated eight times;

1. Untreated Control
2. Spiral cincture (4.0 mm wide) – end of the cincture do not meet
3. Circular cincture (4.0 mm wide) - ends of cincture meet
4. Potassium nitrate foliar spray (3.0%)
5. Spiral Cincture + potassium nitrate
6. Circular cincture + potassium nitrate

Cincturing treatments were applied on the 7 September 2005 either as a spiral or girdle using a hand tool specifically manufactured for the purpose. The potassium nitrate treatments were applied at 42 days following cincturing on the 19 October 2005.

Tree phenology (flush type, panicle emergence, anthesis and fruit set) was monitored and recorded at approximately fortnightly intervals. Harvest commenced on 17 March 2006 and was to continue for approximately two weeks with yields and average fruit sizes recorded. Further harvesting was brought to a halt by Cyclone Larry which struck the coast near Innisfail on the morning of the 20 March. Farm infra structure and fruit laden trees were badly damaged.

Climate variables (temperature, humidity, rainfall and solar radiation) and soil tension at 20, 40 and 80 cm were monitored with an automatic weather station.

17.3 Results

Rainfall, measured at a nearby site (Upper Daradgee), indicated that 916 mm fell in the 4 months following harvest in April 2005. The wet/warm winter weather with the likehood of wet weather continuing into spring presented itself as an ideal time to test the hypothesis that cincturing could be used to control growth and aid flowering. Following the installation of the weather station in October 2005 virtually no rain fell until the end of December. Air temperature, soil temperature and humidity were in the range expected for the wet tropics (Figure 16.1). Soil moisture tension before and in the month after cincturing was high indicating relatively dry conditions existed during the period prior to panicle emergence. An irrigation event in late October briefly reduced soil tensions at 20 and 40 cm to near zero, indicating that soil moisture was readily available (Figure 16.2).

Tree phenology changes were observed regularly from the 7 September at application of cincturing treatments until the 22 November when all treatments were showing near full panicle emergence. General observations were recorded up to the commencement of harvest. The general sequence of events is shown in Table 16.1.

Detailed monitoring of early phenological changes (Figure 16.3) indicates that there are no significant differences between cincturing, KNO_3 foliar sprays and control treatments.

Table 16.1. Trial treatment application and the date of major phonological events.

Date	Phenology
7 September 2005	Mature flush. Application of cincturing treatments
19 September 2005	Mature flush
5 October 2005	Mature flush
19 October 2005	Apply KNO_3 treatments
25 October 2005	Start of flush/panicle emergence
9 November 2005	All treatments; 40-60% panicle emergence
22 November 2005	All treatments; 60-80% panicle emergence
5 December 2005	Start of anthesis (flower opening)
21 December 2005	Full anthesis (flowering) with minor early fruit set
18 January 2006	Full Fruit set
9 February 2006	Fruit filling with minor late fruit set
14 March 2006	Tag trees for harvest records. Fruit near full
16 March 2006	Commence harvesting
20 March 2006	Cyclone Larry – Crop destroyed and orchard badly damaged.

Observations made pre commencement of harvest suggest that tree yields may have been higher on cinctured trees relative to KNO_3 and control treatments. The grower also felt that cinctured trees were bearing higher yields than non cinctured trees. This observation could unfortunately never be tested due to the destruction caused by cyclone Larry. However 10 of the 48 trees were harvested prior to the cyclone and the yields shown in Table 16.2. No conclusions can be drawn from the limited yield data obtained.

Table 16.2. Partial harvest results

Treatment	Mean Yield (kg/tree) and individual tree yields in brackets	Number of trees used to calculate mean
Control	22.8 (3.6 and 41.9)	2
Spiral Cincture	26.9	1
Circular Cincture	22.1 (27.4 and 16.8)	2
KNO_3	14.1 (5.8 and 22.3)	2
Spiral + KNO_3	40.7	1
Circular + KNO_3	23.0 (19.6 and 26.4)	2

17.4 Discussion

Cincturing is a common practice used in the production of longan and particularly lychee. It is believed to control late autumn flushing thereby ensuring a mature shoot is ready to re-flush during florally inductive winter conditions. Menzel and Simpson (1987) reported cincturing stops shoot initiation while the cut remains open. Only recently has cincturing been raised as a possible technique to enhance flowering and fruit set in rambutan (Poerwanto and Irdiastuti (2005).

In north Queensland poor flowering in rambutan is a common problem particularly in years where rainfall is well distributed throughout the year. Although the mechanism behind flower induction in rambutan is not precisely known it is believed to benefit from a period of inactivity in the last flush following maturity of the leaves. In traditional growing areas in SE Asia this generally follows a period of drought. In Thailand, a drought period of 21 to 30 days is believed necessary prior to the application of water to induce floral bud initiation (Anon., 2003). Diczbalis *et al.* (1997) suggest that in the Northern Territory growing environment flowering often follows the onset of the dry season when cool nights commence. They suggested that the trigger for flowering appears to follow the cessation of growth, whether caused by drought or low temperature. A number of authors have suggested that a lack of vegetative growth allows a build up of carbohydrate which improves flower initiation (Scholefield *et al*. 1985, Menzel *et al*. 1989).

The data collected in this trial suggests that floral ignition and subsequent panicle emergence was not influenced by any of the treatments. In this trial panicle emergence commenced from late October for all treatments and occurred in 80% of all terminals by mid November. Panicle emergence coincided with relative “drought” conditions and as such would have favoured floral initiation despite the presence or absence of cincturing treatments. All treatments, including the untreated control flowered well. From mid December soil moisture conditions were favourable for flowering, fruit set and development with increasing and regular rain occurring from late December.

Anecdotal data suggests that cincturing treatments may have positively affected fruit set and yield. Unfortunately this could not be tested due to the untimely arrival of Cyclone Larry and hence the usefulness of cincturing treatments in rambutan remains unresolved.

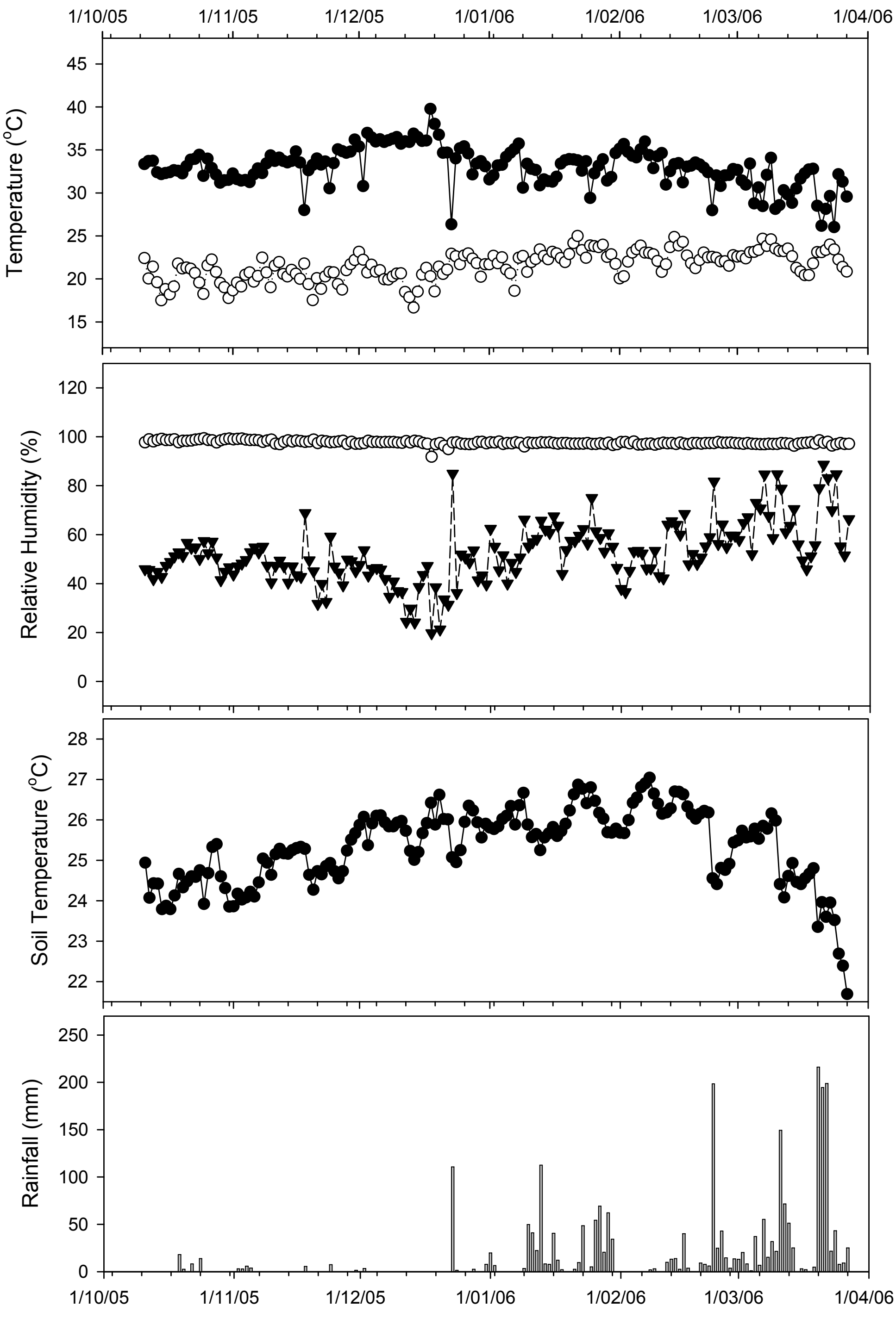


Figure 16.1. Climate data from 12 October 2005 to 1 April 2006. Note: Cyclone Larry struck on the morning of the 20 March 2006.

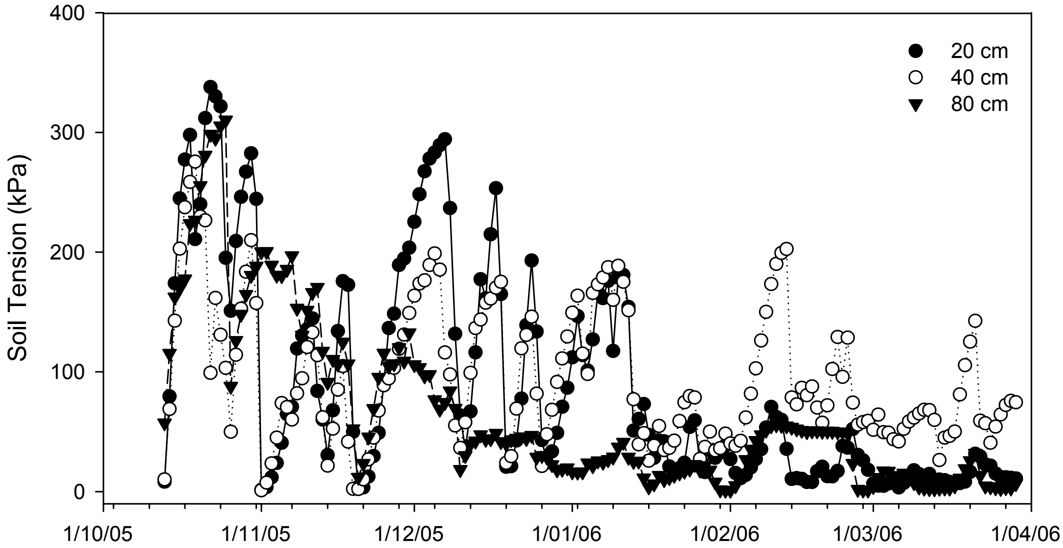


Figure 16.2. Soil tension data from 12 October 2005 to 1 April 2006

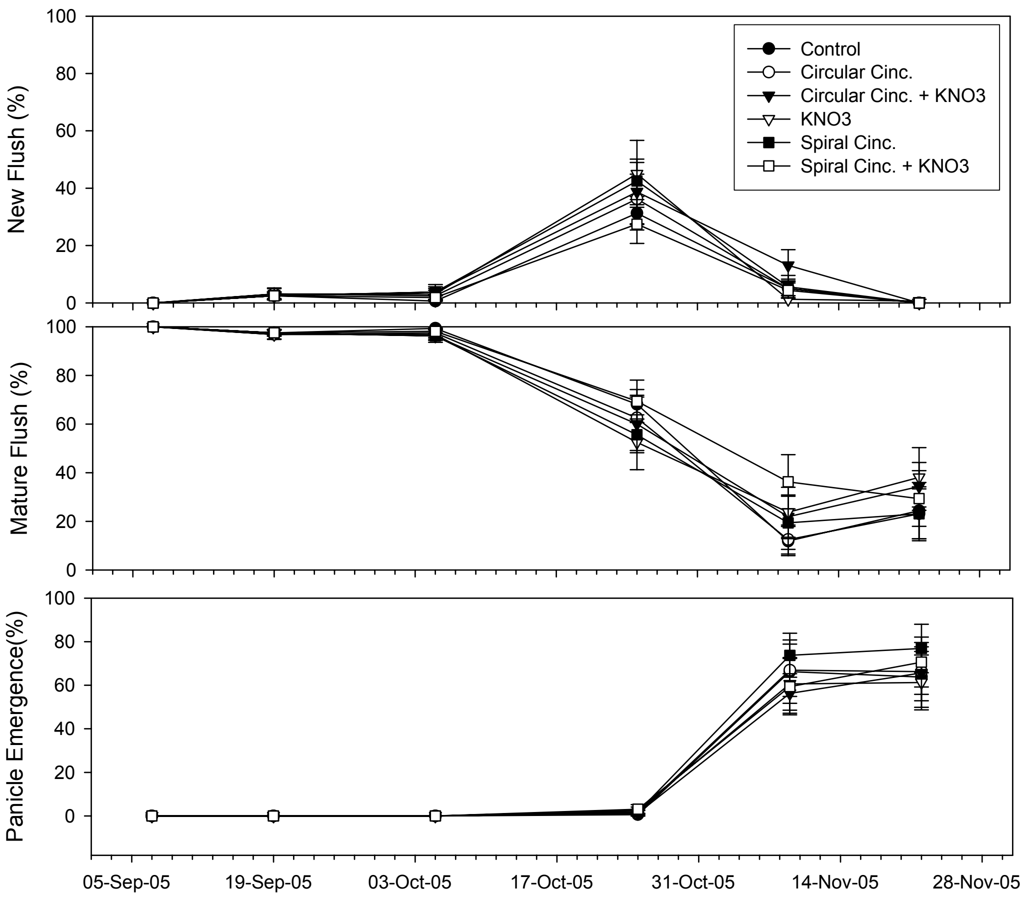


Figure 16.3. Rambutan shoot phenology (mean percentage new flush, mature flush and panicle emergence) for control, cinctured and KNO_3 treated trees.

18. The effect of root pruning on control of vegetative vigour in rambutan

18.1 Introduction

Root pruning is widely used in temperate fruits (apples and stone fruits) to restrict above ground vegetative growth in high density orchards (Arzani *et al*. 1999, Khan *et al*. 1998, Webster and Ystaas 1998). There is little reported literature on the effects of root pruning on tropical fruit crops. However, Ismail (1996) showed that root pruning increased flowering in carambola. We investigated the effect of root pruning in rambutan at two stages;

- root pruning in conjunction with structural pruning to assess the effect on regrowth, tree size and tree productivity relative to untreated trees.
- root pruning immediately pre or at early flowering to assess the effect of root pruning on fruit set, size and yield relative to untreated trees.

18.2 Trial 1

Material and Methods

Root pruning was carried out on mature rambutan trees (*cv*. R156 yellow) following heavy top pruning for tree size reduction. The aim of the root pruning treatments is to test the hypothesis that reducing effective root volume will limit the growth that normally occurs following severe top pruning. A trench digger with a 10 cm wide cut was used to a depth of approximately 40 cm (Plate 17.1). Treatments were imposed at two severity levels (1.5 m and 2.0 m from the trunk) in November 2003, 8 weeks after heavy top pruning. The trenches were back filled on the day of root pruning. Root pruning and untreated control treatments were replicated five times. Top regrowth was visually assessed on a regular basis. In late March 2004 trees were assessed for flush phenology (new, hardening or mature) as well as reproductive activity if any. The length of the last mature flush was measured.

Plate 17.1. Root pruning mature rambutan trees using a trench digger. Roots were cut parallel to the row at two distances from the trunk.

Results and Discussion

Root density

At the time of root pruning it was clearly observed that the density of roots was appreciably higher at 1.5 m from the trunk compared to 2.0 m from the trunk (Plate 17.2). Although not measured the number and diameter of mature lateral roots was much higher closer to the tree. This observation agrees with data presented by Diczbalis *et al*. (1997) where the mean root density of rambutan trees in three NT orchards decreased rapidly with distance from the trunk and depth. In the plate below the surface nature of the trees is clearly observed.

a. Trench at 1.5 m from trunk

b. Trench at 2.0 m from trunk

Plate 17.2. Note difference in severity of root pruning at
a). 1.5 m from the trunk and
b). 2.0m from the trunk.

Vegetative Activity
There were no observed harmful effects of root pruning on tree health or vigour. Trees from both root pruning treatments and control maintained identical vigour and continued to develop new flush. Top growth in root pruned trees was not visibly reduced or retarded compared to untreated trees. On the 23 March 2004 trees were rated for flush activity and the length of the last mature flush (Figure 17.1 and 17.2). For both measurements, flush activity and mean length of last mature flush, there was no significant difference between treatments. There was a trend to more mature flush with correspondingly smaller flush length in the severe root pruning treatment, however, this was small and not statistically different.

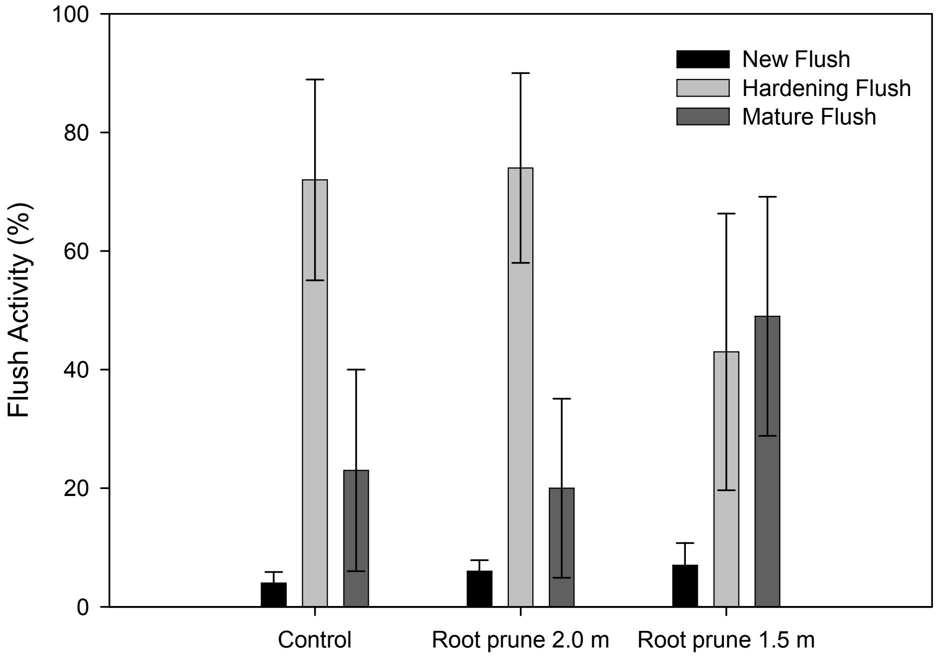


Figure 17.1. Mean tree flush activity on 23 March 2004, 6 months after top pruning and 4 months after root pruning. Vertical bars represent the standard error (SE).

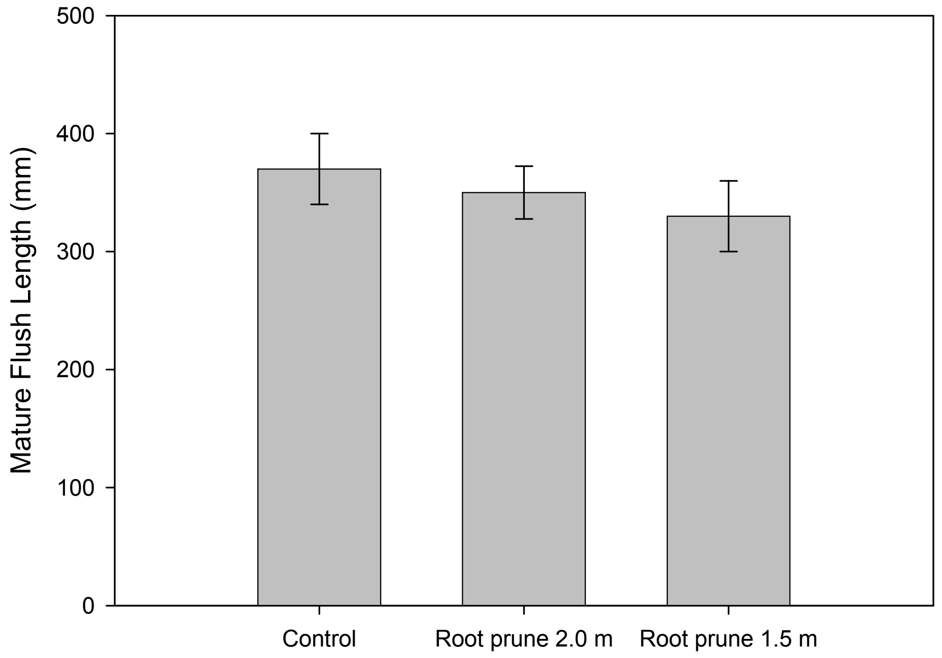


Figure 17.2. Mean mature flush length (mm) for control and two intensities of root pruning treatments. Vertical bars represent the standard error (SE).

Reproductive Activity
Three of the 15 trees observed in the experiment showed minor flowering and fruit set. There was insufficient flowering activity to make any comments about the effect of the root pruning treatment on the reproductive activity of the trees. The heavy structural pruning carried out in September 2003 was to reduce tree height and to open up the centre of the tree. It was not carried out with the aim of achieving flowering and fruiting in the subsequent season.

Next Stage
The purchase of a prototype commercial root pruner based on a rigid shank and disk coulter will allow a more quantitative analysis of the effects of root pruning on regrowth following structural pruning. Root pruning may be able to be used to control vegetative growth or to slow down flush activity and potentially improve flowering. Root pruning has been found to be effective in controlling vegetative growth and enhancing reproductive activity in a range of temperate ornamental and fruiting trees (ornamental trees, Anon. 2005; Apples, Khan *et al.* 1998; Grapes, Ferree *et al.* 2005).

18.3 Trial 2

Material and Methods
A block of young actively growing, 4 year old, rambutans (*cv.* R134) was selected to test the effect of root pruning on vegetative vigour in the period leading up to flowering. The block was planted at a high density with tree spacing 6 m between rows and 4 m between trees within the row. The block consisted of 6 rows in increasing lengths, from 65 to 110 m, containing 15 to 26 trees respectively. Four of the rows were root pruned in July 2004 using a Yeomans tyne preceded by a coulter disc (Plate 17.3a). The root pruning tyne was run parallel to the row approximately 0.8 - 1.0 m from the main stems (Plate 17.3b). The maximum tyne depth was 400 mm.

Flush activity and reproductive behaviour was monitored on four replicate blocks of 5 trees for each treatment. Five shoots on each tree were tagged and monitored for flush status and corresponding length. Measurements were carried from 1 week before root pruning (7 July) and on six occasions post root pruning (22 July, 31 August, 30 September, 14 October, 1 November and 29 November) and ceased at early fruit set. Data are displayed as means with corresponding standard error.

a.

b.

Plate 17.3. a). Commercial root pruner manufactured by Yeomans®;
b). Young high density rambutan rows root pruned.

Results

Flush stage

Trees were actively flushing prior to root pruning and continued to do so after root pruning. The period of observation encompassed one full flushing cycle prior to panicle emergence with some tagged shoots completing two flushing cycles prior to panicle emergence. There was little if any difference in activity between control and root pruned treatments (Figure 17.3). New flush production for both treatments remained relatively active until late September. Panicle emergence commenced in late September and activity peaked from mid October to early November. The percentage of tagged shoots reaching the panicle stage with fruit set was 47% and 56% for control and root pruned treatments respectively. This was the reverse of what was observed for flowering flush where the control trees out performed the root pruned trees for panicle emergence.

Flush Length

Mean flush length measurements show that there was little difference between treatments and flush length was small during the cooler months of July, August and September with rapid elongation of shoots at the commencement of warmer weather and with the commencement of flowering. The final mean panicle length measurement was 239 mm and 276 mm for control and root pruned treatments respectively (Figure 17.4).

Discussion

There was little evidence that root pruning of young actively growing rambutan trees changed shoot flushing patterns, flush length or flush phenology. This result is different from what may be expected based on “conventional” horticultural wisdom and from research experience from temperate fruits. Cut roots were readily identified at the surface of the trenches and the assessment shortly after pruning was that the severity of pruning chosen for the trial was correct.

Reasons for a lack of effect may be;

- The severity of the root prune was insufficient to disrupt the trees. That is; the ripping distance from the centre of the rows was outside the area of peak root activity

- Young actively growing trees are not adversely affected by root pruning and can recover quickly because the bulk of roots were within the root pruned area along the row.
- A prolonged dry season conditions which meant that the development of both root pruned and control trees was similar (ie. control trees were entirely dependent on moisture provided by the sprinkler system and were not able to access moisture outside the wetted area)
- Prolonged cool season which suppressed growth in root pruned and control trees

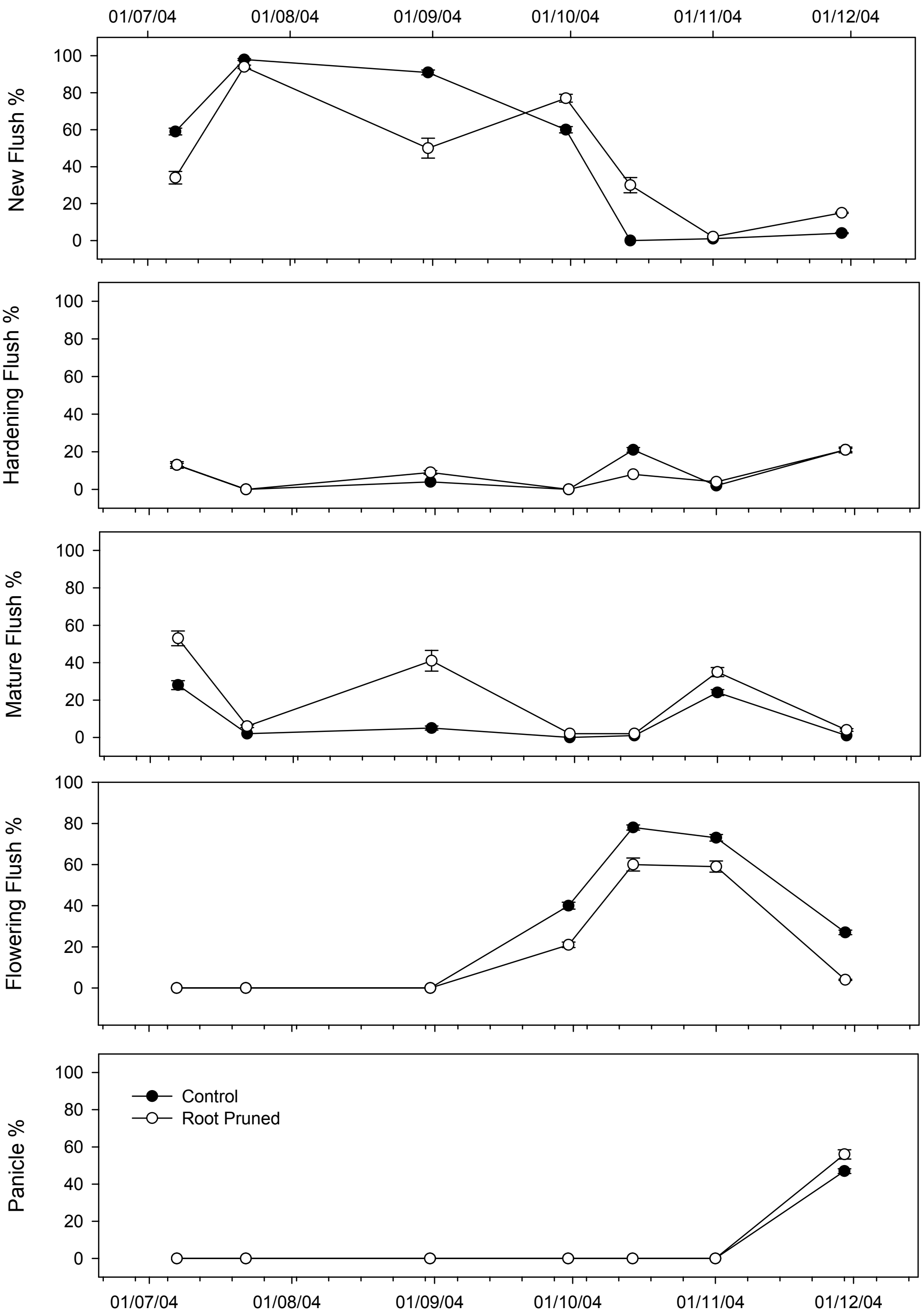


Figure 17.3. Shoot activity (flush – new, hardening and mature; reproductive – flowering (panicle emergence) and panicle with fruit set) ratings for control and root pruned trees. Vertical bars indicate standard error (SE).

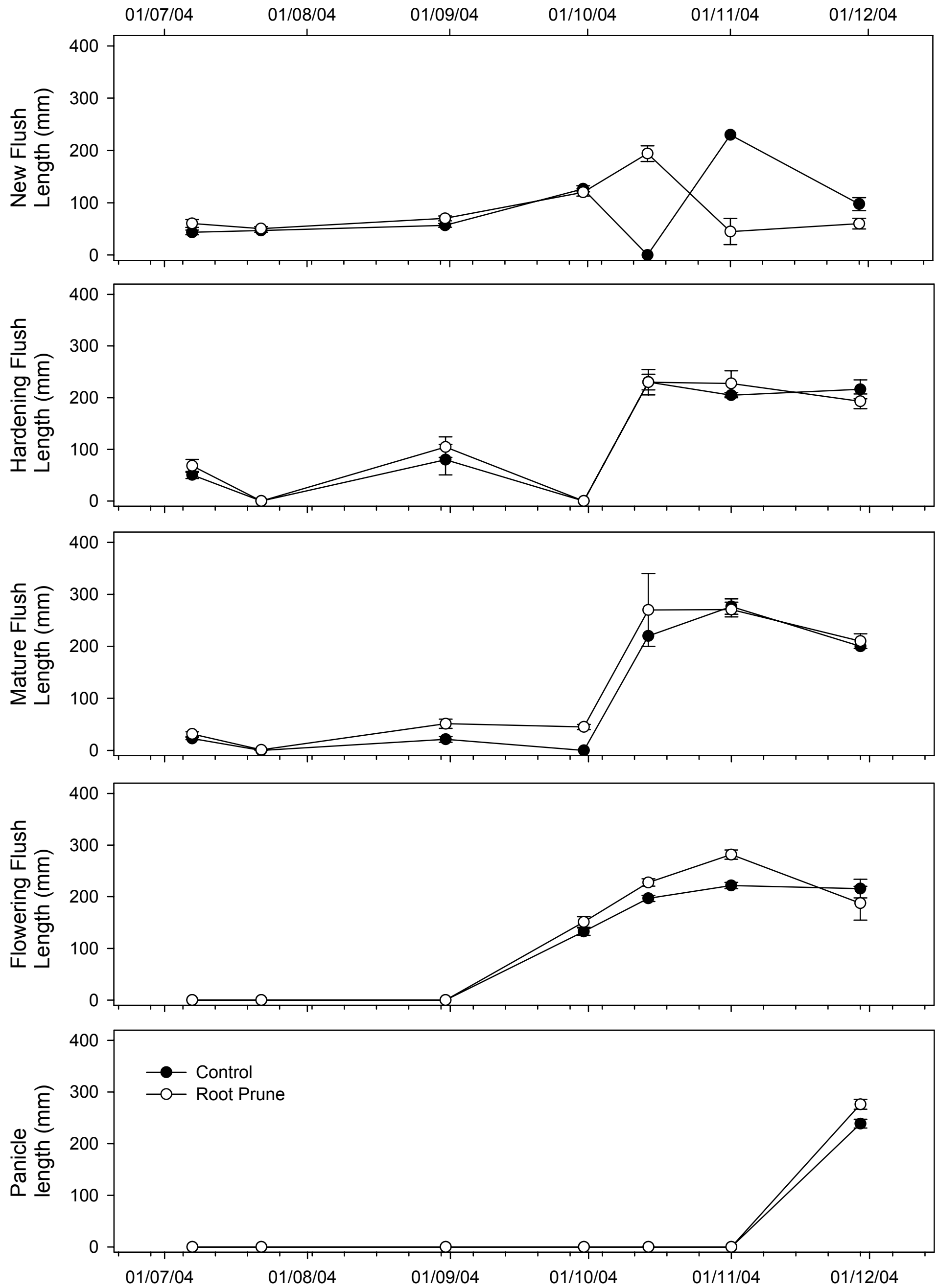


Figure 17.4. Shoot length (flush – new, hardening and mature; reproductive – flowering (panicle emergence) and panicle with fruit set) measurements for control and root pruned trees. Vertical bars indicate standard error (SE).

18.4 Trial 3

Aim
The aim of the trial was to establish the efficacy of root pruning on suppression of vegetative vigour and the maximisation of reproductive terminals on mature rambutans (*cv*. R134).

Material and Methods
A third root pruning trial was established on a mature rambutan orchard which was in a regular yearly cycle of harvest and pruning (heading back). Trees were actively growing when the root pruning was applied in late October 2004. Root pruning was carried out using a Yeomans tyne preceded by a coulter disc (Plate 17.3). The trial consisted of two treatments; control and root pruned. Each treatment was replicated four times and included four trees per replicate. A central tree from each block was selected and 10 shoots tagged. Hence the total number of tagged shoots for each treatment was 40 (1 treatment x 4 replicate trees x 10 shoots/tree). The tagged shoots were monitored on three occasions (18 Jan 2005, 23 March 2005 and 21 April 2005) for flush phenology and flush size. All data is presented as means with associated standard error (SE).

Results and Discussion
The mean shoot phenology (percentage of new flush, hardening flush and mature flush) was similar for both treatments (Figure 17.5) over the tree recording dates. There is an indication that the percentage of tagged shoots which developed flowers although low was approximately double in the root pruned compared to the control treated trees. At the last monitoring date (21 April) 10% of the tagged terminals from the root pruned trees had developed fruiting panicles whereas only 2.5% of tagged terminals in control trees flowered.

The length of new and mature flush and panicles was unchanged by root pruning treatments (Figure 17.6).

In this experiment root pruning did not increase flowering and fruiting relative to control trees. The question remains is this treatment worthy of any further examination as a growth control tool? Supporting further investigation on the effect of the degree and intensity of root pruning is the fact that root pruning at the level conducted in this trial did not cause any growth problems in its own right, hence root pruning closer to the tree may be required to achieve the growth restriction effect that we require. Potential factors influencing the effect of root pruning include; root size, number of roots cut and proximity of the roots to the cut.

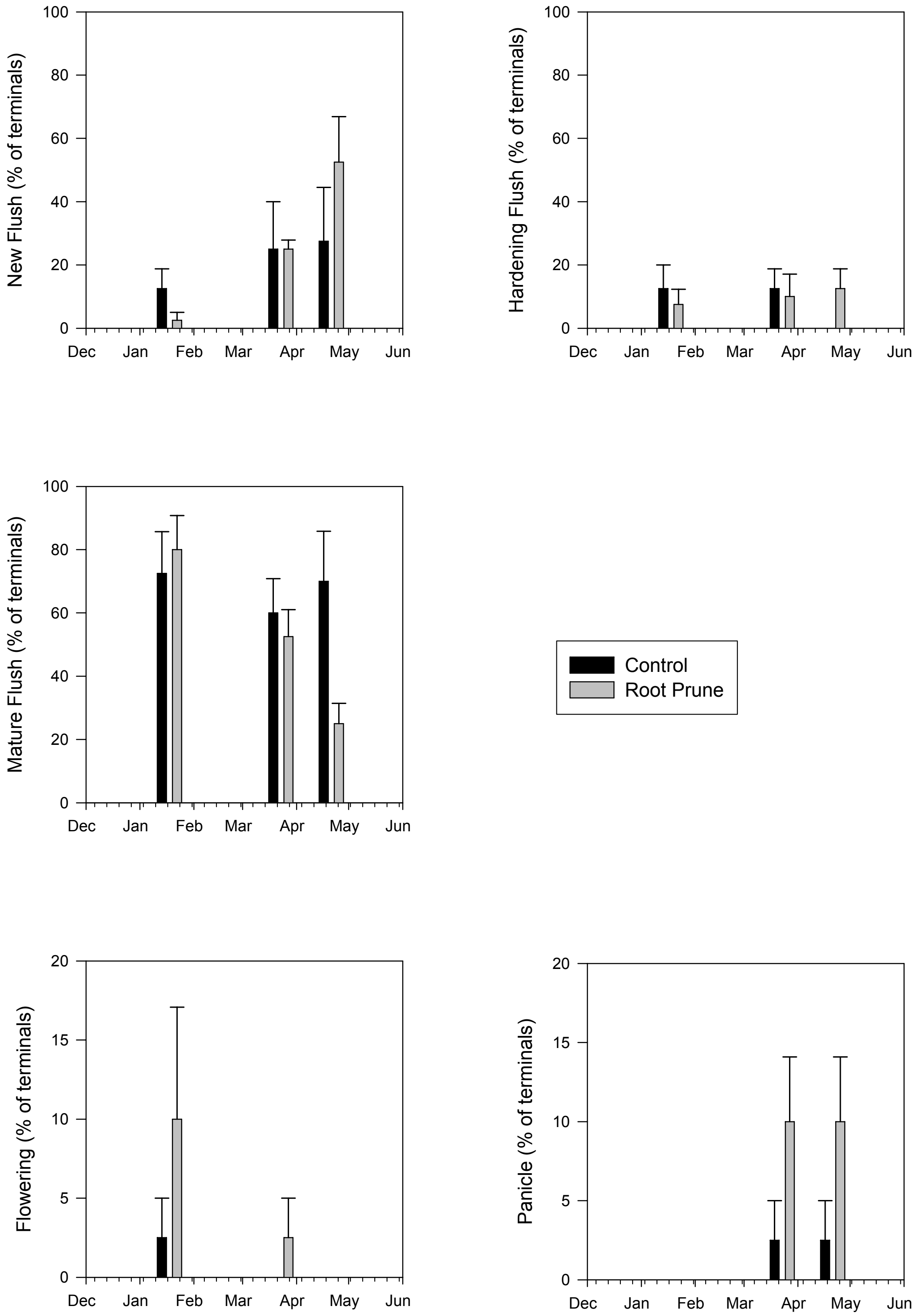


Figure 17.5. Mean New Flush, Mature Flush and Panicle percentage for control and root pruned treatments over three observation dates. Vertical bars represent standard error (SE).

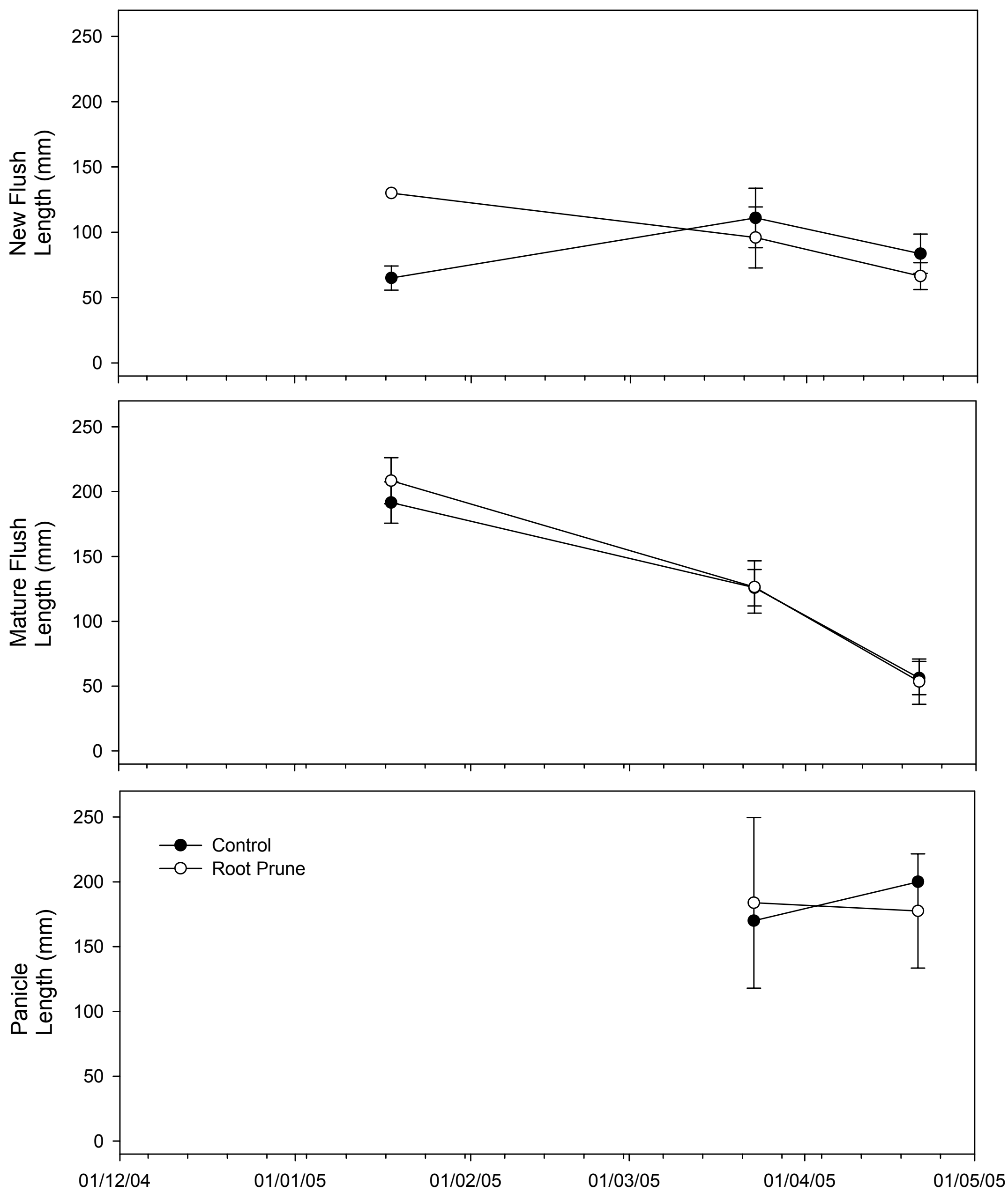


Figure 17.6. Mean flush length for New Flush, Mature Flush and Panicle for control and root pruned treatments over three observation dates. Vertical bars represent standard error (SE).

19. Preliminary examination of the use of Naphthalene Acetic Acid (NAA) on flowering and fruit set in Rambutan.

19.1 Introduction

The rambutan is a terminal flowering crop, which flowers in response to seasonal conditions (Tindal 1994). Valmayor *et al*. (1971) reported that trees propagated from seed result in a high proportion of male flowering trees which do not set fruit; hence vegetative propagation is used to propagate selected female flowering trees. Chin and Phoon (1982) report that rambutan is androdioecious with separate male and hermaphrodite trees. The male tree is seldom found as orchards are usually based on clonal bud wood. In rare cases where wood from the seedling rootstock below the bud graft has been allowed to develop, shoots with male flowers can be clearly seen. Male flowers are characterised by prominent anthers and a rudimentary ovary and no stigma. Hermaphrodite flowers are made up of two flower types. Type one; with prominent anthers and a pronounced but underdeveloped stigma is functionally male. While type two flowers with small underdeveloped anthers and bilocular ovary topped by a prominent bifed stigma are predominately female. Plate 18.1 shows examples of the two flower types (male and hermaphrodite functionally female). The time of opening overlaps hence pollination can occur. This process differs from the other major commercial Sapindaceae crops, Litchi and Longan, which are duodichogamous, where the tree has three stages of flowers (male, female and male) which develop sequentially.

Figure 18.1. Rambutan flower type from left to right; male flower and hermaphrodite flower which is functionally female, note small stamens and anthers.

When flowering occurs in late winter or early spring when night temperatures are commonly less than 18°C the flowers are predominately functionally female and resultant fruit set and development is poor. Panicles develop predominately parthenocarpic fruit which rarely develop beyond 20 mm in diameter (Plate 18.2). This situation is commonly experienced in north Queensland rambutan orchards.

Thai producers routinely use spot sprays of NAA (45 mg/kg) to convert hermaphrodite flowers to functional male flowers to improve fruit set in the cultivars Chompoo and Rongrien (Salakpetch, 2000). In Hawaii, Nagao (2004) reported that the optimum concentration of the potassium salt of NAA for conversion of hermaphrodite flowers to functional male flowers is 90 mg/kg.

Plate 18.2. An example of parthenocarpic fruit (small unfilled fruit) due to poor pollination. Note reference size of normal set fruit.
The Hawaiian work suggests that the most effective time of application is when the first 1/3 of flowers on a panicle begins to open. In both cases trees are spot sprayed weekly over the main flowering period so as only to convert a few (less than 5%) of the developing panicles to functionally male flowers.

There is a need to investigate the efficacy of NAA in north Queensland rambutan orchards to ensure that consistent production can be maintained to supply growing domestic and overseas markets.

This study was established to gain some preliminary data on the efficacy of using NAA in rambutan under north Queensland environmental conditions.

19.2 Trial 1

Materials and Methods
Two mature rambutan trees (*cv*. R134) were selected to test the efficacy of the potassium salt of NAA to change functionally female hermaphrodite flowers to functionally male flowers. The trees had begun panicle emergence in late August of 2004 during a cool winter and early flower opening began on the week of 27 September 2004.

In the week of the 4 October 2004, twenty panicles at the stage of early flower opening were tagged (Plate 18.3). Five panicles with full flower opening (100% anthesis) were sampled and enclosed in a plastic bag. They were taken back to the laboratory so that the flower type and number could be quantified. The remaining tagged panicles were sprayed to runoff, using a hand spray pump bottle, with a solution of 90 mg/kg of the potassium salt of NAA manufactured by Kendon Chemical Pty Ltd.

Treated panicles were sampled at five, seven and twelve days after treatment with NAA, taken back to the laboratory and flower type and number could be quantified.

Application of 90 mg/kg of potassium salt of NAA to early opening hermaphrodite flowers quickly changes flowers from a hermaphrodite to male type (Table 18.1). This effect was still evident 12 days after treatment.

Plate 18.3. Flower opening stage at which NAA application is recommended. Note up to one third of flowers can be at this stage with the remainder closed.

Results and Discussion
This preliminary trial clearly showed the efficacy of the potassium salt NAA in changing the sex of clonal rambutan flowers. This treatment should ideally be an essential management tool for north Queensland rambutan growers where early flowering, during cool conditions, often results in the production of pathenocarpic fruit referred to in the industry as "bally fruit". This problem can severely impact on yield. Other methods used to deal with early flowering, such as panicle removal, on the hope that the latent buds below the initial panicle will flower later can be successful. However, all too often following panicle removal the latent buds break too early and the same problem is experienced again (Sue Smith pers com).

Table 18.1. Effect of foliar NAA application (potassium salt of NAA, 90 mg/kg) at early flower opening on flower number and sex.

Treatment	Measurement time in relation to treatment application.	Number of panicles sampled.	Average male flower number per panicle.	Average hermaphrodite flower number per panicle.
Control 1	0	2	0	181
Control 2	0	3	0	270
NAA	5 days after treatment	5	118	12
NAA	7 days after treatment	4	147	4
NAA	12 days after treatment	4	101	0

The real test of the NAA treatment is successful fruitset where otherwise parthenocarpic fruit would be produced. In the trial above trees in the vicinity of the treated panicles set normal fruit, whereas untreated trees nearby produced parthenocarpic fruit.

In Australia, solutions containing the potassium salt of NAA are not commercially available whereas the sodium salt of NAA is commonly used in apples and pears as a growth regulator to assist with fruit set (Registered Product – Kendon, NAA Stop Drop) at concentrations between 5 and 10 mg/kg. Previous unreported studies in north Queensland had shown that the sodium salt of NAA was also capable of changing the sex of opening hermaphrodite flowers.

The use of NAA requires approval of the Australian Pesticides and Veterinary Medicines Authority (APVMA). A preliminary request for a research permit established the fact that NAA, although registered for a number of uses, does not have an acceptable daily intake (ADI) level for toxicology purposes. It was suggested that we include alternative synthetic auxins in any further efficacy work.

19.3 Trial 2

Introduction
The aim of the trial was to gather efficacy data for the use of the sodium salt of NAA and an alternative synthetic auxin; 3,5,6, Trichoro-2-Pyridiloxyacetic Acid (3,5,6-TPA). Both auxins were evaluated at a range of rates for their efficacy in changing the sex of rambutan flowers.

Materials and Methods
Early flowering rambutans (*cv*. R134) with flowers at the ≈10% opening stage were treated with two synthetic auxins; the sodium salt of NAA and 3,5,6-TPA. The source of NAA was a commercial product; NAA Stop Drop (20 g/L sodium salt of Naphthalene Acetic Acid) manufactured by Kendon Chemical Pty Ltd. While the source of 3,5,6-TPA was Maxim (10% w/w of 3,5,6, Trichoro-2-Pyridiloxyacetic Acid) supplied by Campbell Chemicals Pty Ltd.

Both chemicals were applied at five concentrations (20, 40, 90, 120 and 160 mg/kg) on randomly tagged panicles. Each treatment combination was replicated six times. The male and hermaphrodite flower numbers were assessed on five occasions (0, 4, 7, 11 and 15 days following treatment). Following data gathering, total flower number, percentage male flowers and percentage hermaphrodite per panicle were calculated. The data is presented as means with related standard errors (SE).

Results
Both synthetic auxins produced male flowers but the number of flowers varied with concentration of product applied (Table 18.2). The average total numbers of flowers per panicle was considerably less in treated panicles compared to control panicles with the least average total flower number occurring for panicles treated with NAA. The 3,5,6-TPA treatment at a concentration of 20 mg/kg had the least effect on total flower number of all treatments but produced no male flowers. The NAA treatments produced the highest mean number of male flowers per panicle and double that produced by the 3,5,6-TPA treatment. The NAA concentrations which were the best producers of male flowers ranged from 20 to 120 mg/kg.

Table 18.2. The effect of NAA and 3,5,6-TPA on mean male flowers, mean hermaphrodite flowers and mean total flower number per panicle.

	Concentration (mg/kg)	Mean total male flowers per panicle	Mean total hermaphrodite flowers per panicle	Mean total flowers per panicle
Control		0.5	910.0	910.5
NAA	20	96.7	85.8	182.5
	40	84.8	74.3	159.2
	90	46.5	33.2	79.7
	120	89.8	53.0	142.8
	160	34.7	31.3	66.0
Av. NAA		*70.5*	*55.5*	*126.0*
3,5,6-TPA	20	0.0	869.3	869.3
	40	14.7	423.8	438.5
	90	65.7	80.5	146.2
	120	77.8	47.2	125.0
	160	6.8	77.2	84.0
Av. 3,5,6-TPA		*33.0*	*299.6*	*332.6*

Figure 18.1 shows the percentage of male flower development relative to the total numbers of flowers per panicle and the timing of male flower production. In NAA treated panicles male flower production reached a peak in seven days after treatment and fell away sharply thereafter. Maximum male flower production in 3,5,6-TPA treated panicles occurred at 11 days after treatment and fell sharply at 15 days after treatment for the 40 and 160 mg/kg concentrations but remained at a similar percentage of total flower production for the 90 and 120 mg/kg.

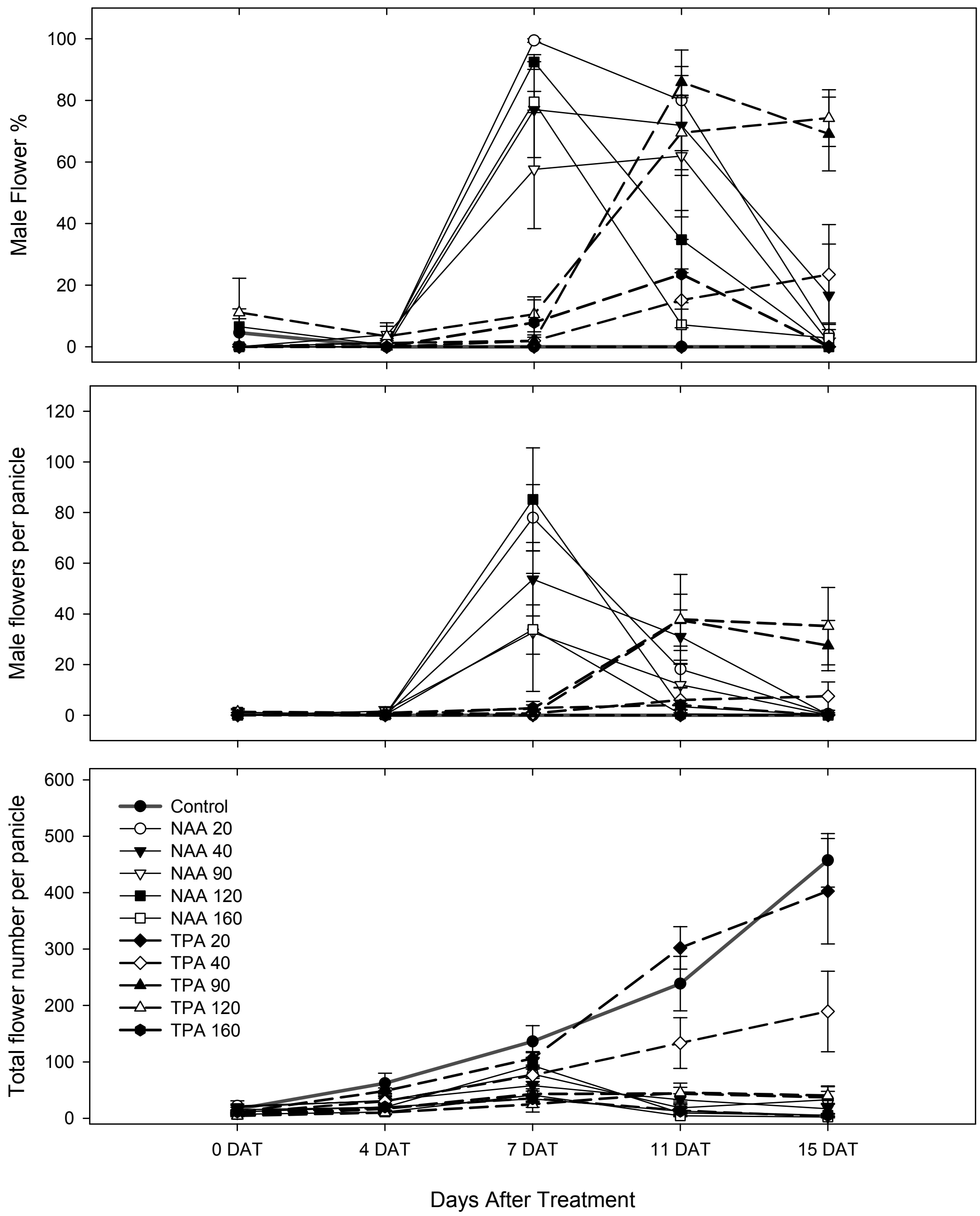


Figure 18.1. The effect of NAA and 3,5,6-TPA on male flower percentage, mean male flowers per panicle and total flower number. Vertical bars represent the standard error (SE).

Figure 18.2 shows the reverse situation for the percentage of hermaphrodite flowers per panicle. The mean number of hermaphrodite flowers per panicle peaked at 15 days after treatment for the control and 3,5,6-TPA 20 and 40 mg/kg treatments. In the remaining eight treatments there was no distinct period of flower production. This is a reflection of the mean total flower production pattern.

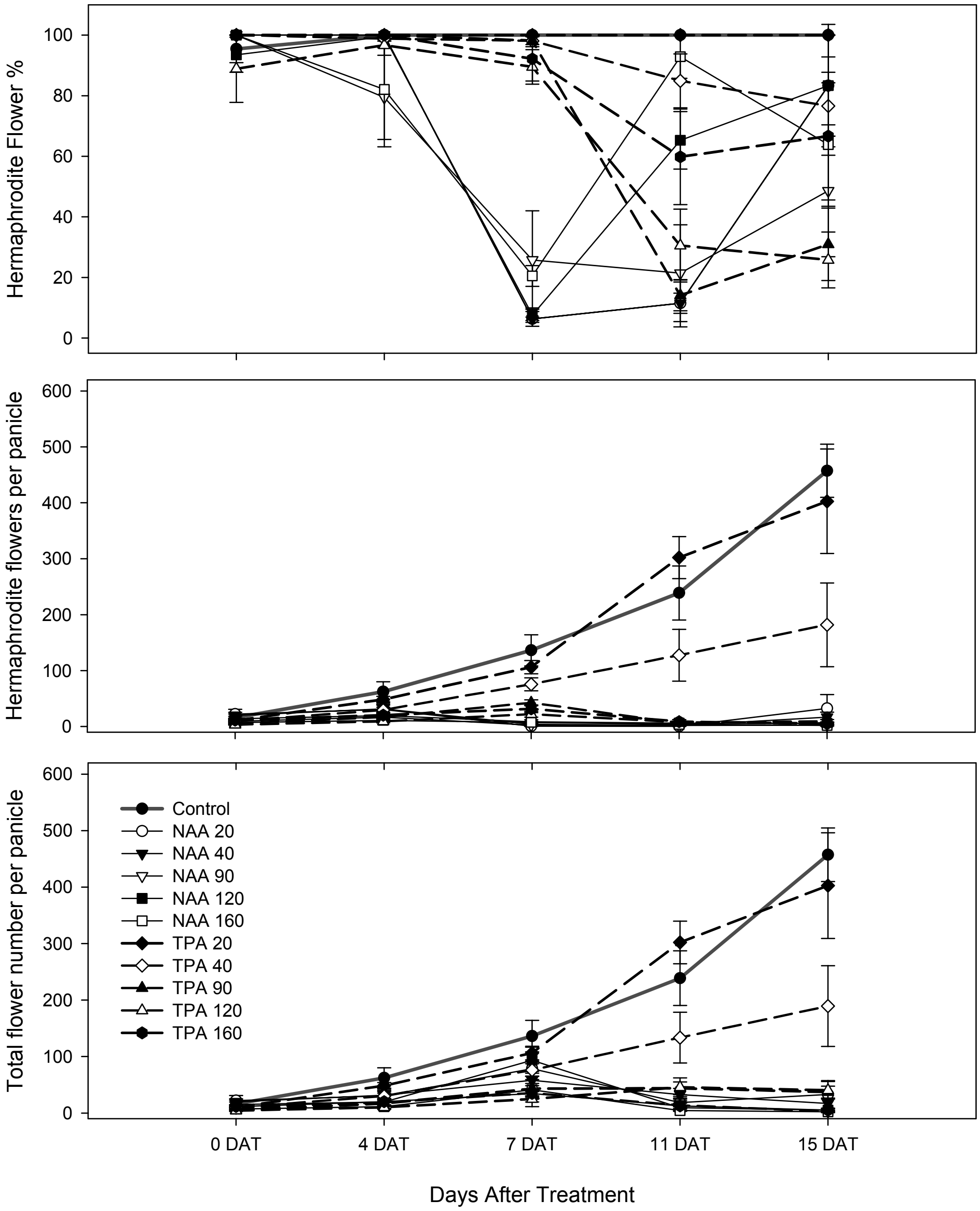


Figure 18.2. The effect of NAA and 3,5,6-TPA on mean hermaphrodite flower percentage, mean hermaphrodite flowers per panicle and mean total flower number. Vertical bars represent the standard error (SE).

Discussion

The use of NAA to ensure the production of male flowers has the capacity to markedly improve the productivity of rambutan trees, particularly in years and orchards where seasonal and climatic conditions are conducive to early flowering. The trials above clearly indicate that a low dose application of NAA or 3,5,6-TPA will convert developing rambutan flowers from a hermaphrodite to male form thus enhancing the potential for successful pollination and subsequent fruit set. NAA appears to be successful particularly at concentrations as low as 20 mg/kg. In this work chemical burn was observed at 11 days after treatment on the NAA treated panicles at 90, 120 and 160 mg/kg and also on the 3,5,6-TPA treated panicles at 160 mg/kg. The 3,5,6-TPA treated panicles at 120 and 160 mg/kg also appeared slightly stunted relative to panicle from the remaining treatments.

Both chemicals impact on the total number of flowers produced per panicle relative to control (untreated panicles). This suggests that the auxin application may cause drop of developing florets because all the panicle at the time of treatment application were at a similar stage of development and hence theoretically had the potential to produce similar total flower numbers.

The results obtained in this study match those obtained by Kawabata *et al*. (2004). These researchers further identified a varietal response to the application of the potassium salt of NAA. The cultivars Rongrien, Jitlee and R7 were the most responsive with 80 to 100 male flowers produced per panicle, where as R156 Y, R9b and R134 had a midrange response (30 to 60 male flowers per panicle). Remaining varieties such as Binjai, R162, R156 R, R137 exhibited a low response to NAA producing less than 20 male flowers per panicle. If this response also applies to the same varieties in Australia this could have implications for management of flowering in mixed cultivar orchards.

No studies are available which examine the efficacy of the treatment on fruit set; that is comparing the fruit set in treated and untreated orchards. Anecdotal experience from experimental work in north Queensland and Hawaian orchards certainly suggests that the application of NAA to less than 5% of panicles in a orchard will result in "good" fruit set under climatic conditions where poorly developed parthenocarpic fruit would be expected (cool night temperatures). The efficacy of the chemical on fruit production needs to be quantitatively confirmed.

Given the lack of an acceptable daily intake (ADI) for NAA and the potential lack of availability of a permit for the use of NAA means that research should be carried out to screen potential replacement chemicals. This preliminary study shows that the synthethic auxin 3,5,6-TPA, which has a ADI, although not as effective may be a suitable replacement.

Further work is required in this important area of research which impacts directly on orchard and industry productivity.

20. Conclusions/Recommendations

Management of pruning still remains an important issue, particularly as there is a need to maintain tree height to a level which allows for economical picking and netting for crop protection purposes. Our studies suggest that trees require 16 months or more following heavy pruning to begin to flower and fruit with 21 to 25 months being necessary for the highest yields to occur. The earlier in the calendar year that pruning can take place the more likely trees are to recover and flower in the next season. Early pruning (January to March) however will be inappropriate because in most cases trees are still bearing fruit with harvest operations generally commencing from mid February. The other alternative is for pruning to occur from late August when warming spring temperatures allow the new post pruning flush to develop quickly. Growers need to consider managing pruning so as to avoid heavy pruning the entire orchard in the same year. Growers may consider splitting their rambutan orchard into four with heavy pruning carried out on a block of trees every four year. In the alternative years trees are either not pruned or lightly pruned. This form of management ensures that half of the orchard is in a state of growth that allows for full flowering and fruit-set to occur (Table 13.5).

The use of both physical (cincturing and root pruning) and chemical (paclobutrazol, uniconazol, prohexidione calcium and mono potassium phosphate) growth regulators failed to significantly alter vegetative growth and flowering patterns. There were indications that both of the physical treatments and paclobutrazol had minor effects on growth and subsequent flowering but the effects were not strong enough to recommend them as treatments. These results are at odds with what has been recorded on other crops and in particular the use of paclobutrazol on rambutan in Indonesia. On large trees, the application of a cincture did not show any adverse effects. There was anecdotal evidence from the last trial that cinctured trees may have had a higher fruit set relative to control trees, however this could not be quantitatively confirmed due to the trial being damaged by the advent of Cyclone Larry. Root pruning was another physical growth regulating technique that did not significantly enhance flowering yet there were indications that the treatment may have a small effect on vegetative growth. Root pruned trees did not suffer any deleterious effects and hence the “intensity” of the treatment may have to be examined more closely

The use of synthetic auxins to ensure the production of male flowers has the capacity to markedly improve the productivity of rambutan trees, particularly in years and orchards where seasonal and climatic conditions are conducive to early flowering when low temperatures inhibit the development of functionally male hermaphrodite flowers. The results of trials conducted during this project clearly indicate that a low dose application of NAA or 3,5,6-TPA will convert developing rambutan flowers from a hermaphrodite (functionally female) to male form thus enhancing the potential for successful pollination and subsequent fruit set. NAA appears to be successful particularly at concentrations as low as 20 mg/kg. The auxin 3,5,6-TPA was more effective at higher concentrations (90 and 120 mg/kg). Further work needs to be carried out to ensure the efficacy of the treatment on subsequent fruit set and orchard productivity.

20.1 Implications

Research into pruning and manipulation of floral induction in rambutan suggest that there is no easy solution to managing pruning and subsequent flowering in the north Queensland growing environment. Unlike the use of $KClO_3$ in longan there is no flowering 'switch' yet discovered for rambutan. This project has improved the understanding of the effects of pruning time on subsequent regrowth and flowering. Unfortunately none of the trialled pruning times significantly improved the chances of obtaining flowering and fruit set in the subsequent season. This leads to the conclusion that growers will need to consider staggering their heavy pruning operations through out the orchard if they wish to ensure some production in every year. The results clearly indicated that nearly two full seasons of growth was required before growing terminals were at a stage that flowering could occur.

None of the growth regulating techniques trialled significantly improved flowering yet there were indications that the physical growth regulating techniques (cincturing and root pruning) may warrant further investigation. Growth regulating chemicals other then those trialled should be tested as they become available.

The use of synthetic auxins to manipulate the sex ratio of rambutan flowers did show strong promise. This technology could significantly improve the productivity of early flowering orchards. Further work will be required to confirm the efficacy of the technology as well as to seek product registration.

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