Hort Innovation

Final Report

Macadamia – Propagation and Precocity

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Delivery partner:

Plant & Food Research Australia Pty Ltd

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MC13014

Project:

Macadamia – Propagation and Precocity – MC13014

Disclaimer:

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Content

Summary

Tree cost and time to production of first commercial yields are barriers to adoption of high-density planting systems with many tree fruit crops. Planting more trees per hectare as with high-density plantings will increase early yields from new blocks but the additional cost of the extra trees can be a disincentive for growers to follow this path. Also, if trees planted at high density do not reach full production until after they have become crowded then there is no benefit in having more trees per hectare. So precocity, encouraging higher yields from young trees, is important. This project, targeted at the Australian macadamia growers and nurseries, will be relevant to other fruit sectors. It has investigated options to reduce the purchase cost of trees, reduce the cost to establish trees in the orchard, and evaluated a range of management techniques to improve tree structure, promote flowering and thus reduce the time to first commercial harvest for young macadamia trees.

Young macadamia trees exhibit very strong apical dominance with almost complete suppression of axillary shoot growth. This makes it difficult to produce trees with a strong fruiting framework and results in considerable expense for growers to prune and train young trees. Projects involving the use of plant growth regulators (PGRs) to overcome apical dominance in the nursery were unsuccessful. However, a second PGR product was identified that could be used to stimulate already-dormant epicormic buds into becoming active and producing new shoot growth on bare sections of wood on larger trees. This might be useful as part of a programme to rejuvenate older orchards.

Working with a commercial grower near Maryborough in Queensland, the project also evaluated the growth and productivity of micro-grafted, mini-grafted, traditional-grafted and own-rooted cutting-grown trees. Trees were planted in September 2015 in a large fully replicated field trial with two scion cultivars ‘A203’ and ‘741’. The ‘A203’ trees produced their first small crop in 2018 and the ‘741’ trees will produce their first crop in 2019. Results show that tree size (trunk diameter and canopy volume) and yield were similar on the ‘A203’ trees in 2018. A similar result was found with the ‘741’ trees in terms of tree size and the number of floral racemes in spring 2018. The implications of these data are that the less-expensive mini-grafted trees are just as early to come into production as traditional grafted trees.

Growers spend considerable time in the orchard training, pruning and staking young trees during their establishment phase to prevent the trees becoming top-heavy and thus less stable in strong winds. Treatments using a third PGR product were evaluated on ‘A16’, ‘A203’ and ‘741’ trees on H2 mini-grafted rootstock. Macadamias proved to be highly sensitive to this PGR with half label rates being sufficient to reduce shoot extension growth on young trees and avoid one and possibly two rounds of pruning and training in the first two years of growth without compromising yield. In fact there were indications that treatments which created a smaller, denser canopy increased the propensity of these trees to produce flowers. This is counter-intuitive as one would expect fewer flowers with less light inside a dense canopy. However, it does fit with the overall bearing pattern of macadamia trees, in which flowers are consistently produced on the “inside” of the tree canopies, a zone with relatively low incident light.

Increasing yields from young trees and thus reducing the time to first commercial harvest is a key target for growers establishing new macadamia orchards. While growers will generally harvest the lighter crops on young trees by hand, once the crop reaches a critical volume then machine harvesters are used, which is considerably more cost effective than hand harvesting. Trunk girdling three- and four-year old ‘344’ macadamia trees was evaluated at a commercial orchard near Knockrow in northern New South Wales. Results were that with 4-year-old trees we were able to double the crop to over 2 kg/tree NIS (nut in shell) and thus advance timing of the first commercial harvest from these trees by 1 year, with potential to harvest by machine. This is an important result for industry that warrants further investigation across different sites and with different cultivars.

Tech transfer and extension activities during the 4 years of this programme have included 27 meetings with industry representatives (growers, nurseries, consultants, researchers and AMS staff); made 8 presentations to industry workshops/conferences; and published 2 industry articles, 1 scientific poster and 1 related scientific paper.

Keywords

Macadamia; propagation; flowering; precocity; productivity; plant growth regulators; pruning; girdling.

Introduction

The Macadamia Industry Strategic Investment Plan 2014 – 2019, highlights five areas of key investment, these include 'identifying and advocating opportunities for orchard development and expansion' and investing in 'future orchards and new orchard systems'. The actions stated by industry to achieve these outcomes include:

- Integration of all relevant research and practice to deliver the next generation of orchard management systems
- Participation and involvement in the multi-industry "small trees" programme
- Continued research to develop a sound understanding of macadamia tree physiology
- Development of a multi-disciplinary, multi-agency future orchard systems programme
- Develop economically viable replanting technologies and practices.

The plan also recognizes the need to 'develop nursery propagation systems that can meet industry requirements'. By achieving the outcomes of the Plan, it is expected that there will be:

- Greater confidence to invest in new orchard development
- Expanded production base and increased production
- Improved orchard productivity
- Greater adoption of best practices and innovation including cultural and biological crop protection practices; reduced soil loss; tree architecture and orchard design; and mechanisation.

This programme "MC13014 Macadamia – propagation and precocity" was designed in consultation with industry consultants, growers, nurseries and other researchers to provide a mechanism to address, in part, the action and outcomes articulated in the Plan. In particular the programme was designed to focus on the early establishment of orchards and techniques to reduce the time taken to the first commercial harvest of new macadamia orchards. Expected benefits would include improved economics for investing in new orchards and replanting existing orchards. As such, the programme was designed to be complementary to the Small Trees Project (being undertaken by DAFF Queensland with Hort Innovation support) which is focused on long-term orchard performance and help to build the desired 'multi-disciplinary, multi-agency future orchard systems programme', as outlined above.

The main thrust of the business case was to provide reliable data to assist macadamia growers make decisions regarding establishment of new "intensively planted" orchards that have early, high yields, thus ensuring rapid return on investment.

The initial focus was on the development of new propagation systems and means to increase the availability and to reduce the purchase cost of trees for growers establishing new orchards. It was identified that a major problem for growers and investors was that if they wanted to plant out new orchards in Australia they would have to wait at least two years for the nursery to supply trees. Mini-grafted trees had been proposed as a faster and less expensive propagation technique than the traditional-grafted trees, but no-one had actually confirmed that the mini-grafted trees would perform in the orchard as good as or better than traditional-grafted trees. Micro-grafted trees were considered as an even better option to mini-grafted trees. Hence the initial stages to the program were to evaluate the performance of these new tree types in the nursery and in the orchard and then to focus on means to promote higher productivity and reduced management costs for establishing young trees with the ambition being to reduce the time taken for new orchards to produce their first commercial harvest.

Methodology

This project was targeted at growers, investors and consultants establishing new macadamia orchards and requiring a quick return on investment to cover establishment costs, including the costs of trees, and reduce the time to reach break-even point. By focusing on the tree propagation and establishment phase in orchard development, the project supported the larger "small trees" project funded by Hort Innovation and delivered by the Queensland Government Department of Agriculture and Fisheries (DAFQ) and the Queensland Alliance for Agriculture and Food Innovation (QAAFI) which focused on new growing and orchard systems design. A proposed outcome for the project was to extend the knowledge and capacity of the Australian macadamia industry in regard to innovative nursery management and plant establishment techniques that are being used in other horticultural industries with success but were not yet tested and adopted by the Australian macadamia industry.

Methodology in this programme was developed around three themes: propagation, tree establishment and precocity. The propagation projects involved evaluation of plant growth regulators (PGRs) in the nursery to help overcome apical dominance and stimulate axillary shoot production, and evaluation of different tree types being produced by nurseries (micro-grafted, mini-grafted, traditional grafted and cutting-grown trees). The tree establishment projects focused on ways to produce trees with a better balance between shoot growth and trunk development to prevent the trees becoming top-heavy and thus less stable in strong winds. Trunk girdling was evaluated as a means to promote earlier cropping (precocity) on young trees.

Propagation:

Planting more trees per hectare as with high-density plantings will increase yields from new blocks but the additional cost of the extra trees can be a disincentive for growers to follow this path. In this project we compared the performance of different tree types that have the potential to reduce propagation time and thus reduce tree costs to the grower. While traditional grafted macadamia trees take 24 months from germinating the seedling rootstock to grafting and field planting, mini-grafted trees take 10-12 months from seed and the much newer micro-grafting technique can take only 8-12 months (Appendix I). While the original plan for this project was to work alongside a commercial nursery to compare micro-grafted and mini-grafted trees with traditional grafted trees, this plan needed to be revised as the nursery changed ownership and was no longer able to supply sufficient quantities of the micro-grafted trees. Nevertheless we were able to begin evaluation of plant growth regulator PGR1 on micro-grafted trees in an attempt to stimulate branching and development of a central leader tree (Appendix II). This product has been used previously in the apple and avocado industries to improve tree structure. We also evaluated PGR2 as a means to stimulate axillary shoot production from dormant “epicormic” buds on the trunks of traditional grafted trees (Appendix III).

Tree establishment:

The main task here was to compare the performance of mini-grafted and traditional grafted trees in the first three years after planting. As it turned out we were also able to include two grades of cutting-grown trees of the same varieties (‘A203’ and 741) in this project (Appendix IV). The mini- and traditional grafted trees were on H2 seedling rootstocks.

Macadamia growers spend considerable time in the orchard training, pruning and staking young trees during their establishment phase to prevent the trees becoming top-heavy and thus less stable in strong winds. Secondary growth (thickening) of trunks on young macadamia trees is unusually slow compared with most tree fruit crops. Various projects involving pruning, training and PGR3 were established with a focus on improving tree structure (trunk diameter vs canopy volume). Three levels of pruning removing 50%, 80% and 100% of the canopy of young trees were evaluated (Appendix V). A preliminary tree training project involving pinning down the trunks of young trees to promote vigorous growth from epicormic buds above the graft union and produce a stronger trunk with more axillary shoot growth was also implemented (Appendix VI). Two projects evaluating PGR3 to inhibit shoot growth and thus avoid pruning costs were also established on one- and two-year-old trees (Appendix VII).

Precocity:

The first crop on young macadamia trees is often not sufficient to warrant a full commercial harvest using mechanical harvesters and so growers are faced with the much higher cost of hand harvesting. Reducing the time to first commercial harvest is therefore a major incentive for growers wanting to achieve earlier returns on their investment and for the orchard to reach break-even. Trunk girdling has been used in several tree and vine crops to stimulate flowering and productivity. Previous attempts with macadamia have focused on girdling of branches on larger trees, rather than young trees about to produce their first commercial crop.

In this project, two trunk girdling treatments were applied in March 2016 to 3- and 4-year-old trees to promote earlier flowering and cropping (Appendix VIII). The 3-year old trees were planted in June 2013 and the 4-year-old trees in February 2012.The cultivar used was ‘344’ grafted onto H2 seedling rootstocks. While the 3-year-old trees had not produced any crop at the time of treatment, they were expected to produce at least some flowers in spring 2016. Their first significant crop was not expected until summer 2018. The 4-year-old trees had a small crop (<10 nuts/tree) at the time of girdling and were expected to produce their first significant crop in summer 2017.

Project review and tech transfer:

All project work in this programme was undertaken on private nursery or grower sites with regular communication and exchange of information regarding preliminary results and future directions with owners and workers

(Appendix IX). Regular consultation on project design and progress also included senior macadamia consultants and growers and researchers involved in the "small trees" programme, in particular via the annual Consultants Workshops organised by the Australia Macadamia Society (AMS) and the Macadamia Physiology Workshop organised by Hort Innovation. Presentations were made to these workshops as well as to the AMS Annual Conference. A full list of these project activities/outputs is provided in the following section.

Outputs

Industry meetings:

15 August 2015	Small trees meeting, invited presentation on "small trees" research UQ Brisbane QLD
19 August 2015	Met with David Bell to discuss supply of cutting-grown trees for Maryborough trial site, Beerwah QLD
27 August 2015	Met with Ross Burgess, Macadamia Direct to discuss macadamia research and potential trial sites, Knockrow NSW
27 August 2015	Met with Rob Colefax to discuss macadamia research, Alstonville NSW
28 August 2015	Stahmann Farms Pecan "propagation and precocity" meeting, Moree NSW
11 October 2015	Meeting with Scott Alcott (Macadamia Farm Management) and Adrian Forrest re supply of mini-grafted trees for research trials, Bundaberg QLD
14 October 2015	Meeting with Kim Wilson, Ray Norris and Chris Searle (Macadamia nurserymen and consultants) to discuss project, Lismore
15-17 October 2015	Macadamia Industry Conference, Lismore. Invited Small trees presentation.
10 December 2015	Met with Robbie Commens (AMS) and Andrew Pierce (Consultant) to view research trials at Maryborough QLD
2 February 2016	Met with Scott Alcott, David Nel and David Harris to discuss macadamia research trials at Maryborough QLD
22 March 2016	Met with Robbie Commens (AMS) to review girdling trial data at Knockrow NSW
28-29 March 2016	Attended Australian Nut Congress, Sydney
6 June 2016	Met with John Wilkie (DAFQ) to review research program at Maryborough QLD
7-8 June 2016	Attended AMS Macadamia Consultants Workshop, Virginia QLD
9 July 2016	Met with NSW Dept of Agriculture staff at Alstonville NSW to discuss potential collaboration on macadamia research
10 July 2016	Met with Jolyon Burnett (CEO) and Robbie Comments from the Australian Macadamia Society in Lismore NSW to review macadamia research and identify potential grower collaborators for future field trials
11 August 2016	Met with Scott Allcott from Macadamia Farm Management in Bundaberg QLD to establish new collaborative trials on their macadamia plantation at Maryborough
19 August 2016	Met with David Bell from Hidden Valley Nursery in Beerwah QLD to establish collaborative trials to evaluate clonal macadamia trees
27 August 2016	Met with Ross Burgess from Macadamia Direct in Lismore NSW to discuss new collaborations on macadamia research
6 June 2016	Met with John Wilkie from DAFF Queensland in Maryborough QLD to review our macadamia research projects and opportunities for future collaborations
8 June 2016	Attended Australia Macadamia Society Consultants workshop in Brisbane QLD to present summary of our macadamia productivity research
19 October 2016	Attended AMS Conference in Caloundra QLD
28-29 Mar 2017	Represented PFR at Australian Nut Industry Congress, in Melbourne

6-7 June 2017	Attended Australian Macadamia (AMS) Society Macadamia Consultants Workshop to present data on young tree productivity trials
1-2 August 2017	Attended Hort Innovation Macadamia Physiology Workshop in Bundaberg QLD to provide invited presentation on macadamia tree physiology and priorities for future research
13-14 September 2017	Attended Macadamia Symposium in Hilo, Hawaii
13-15 November 2018	Attended AMS Conference in Gold Coast QLD.

Presentations:

Thorp TG. Macadamia canopy management ... a fresh perspective on our opportunities. Invited presentation to Australian Macadamia Society Annual Industry Conference, Thursday 16 October 2014

Thorp TG. Small trees research – PFR's experience. Invited Presentation to DAFFQ and UQ "small trees" workshop, Brisbane, 15 August 2014

Thorp TG. Macadamia – propagation and precocity. Presentation to Annual AMS Consultants Meeting, Brisbane, 7 June 2016

Thorp TG. Macadamia – propagation and precocity. Presented to Australian Macadamia Society Annual Conference in Caloundra, 19 October 2016

Thorp TG. Macadamia – propagation and precocity. Invited presentation to Annual Australian Macadamia Society Consultants Meeting in Brisbane, 7 June 2017

Thorp TG, Smith AML. Use of trunk girdling to advance timing of first commercial harvest in macadamia. Presentation to 2017 International Macadamia Research Symposium in Hilo, Hawaii, 13–14 September 2017

Thorp TG. Macadamia tree physiology. Invited presentation to Hort Innovation Macadamia Physiology Workshop, Bundaberg, 2 August 2017

Thorp TG. Macadamia tree physiology. Invited presentation to AMS Conference in Gold Coast, 15 November 2018

Industry articles:

Thorp TG. 2017. R&D Update: Meet the Researcher Grant Thorp. Australian Macadamia Society News Bulletin, Winter 2017, 45/2: 46-47

Thorp TG and Smith AML 2018. Advancing the timing of first commercial harvest using trunk girdling. Australian Macadamia Society News Bulletin, Spring 2018: 75-77

Scientific poster and papers:

Thorp TG and Smith AML. 2018. Trunk girdling: reducing the time to first commercial harvest in macadamia prepared for AMS Conference in Gold Coast, 13-15 November 2018

Howlett B, Read S, Alavi M, Cutting B, Nelson W, Goodwin R, Cross S, Thorp T and Pattemore D 2018. Cross-pollination can enhance macadamia yields, even in the presence of branch-level resource allocation limitations. HortScience (accepted)

Outcomes

This project has contributed to the debate around new nursery propagation systems that meet industry requirements by confirming that the more cost-effective mini-grafted macadamia trees are suitable for establishing new orchards as an alternative to traditional-grafted trees. Project outcomes will include greater confidence for investors to invest in new orchard development and help expand the production base in Australia.

Mini-grafted trees have a shorter propagation cycle than traditional grafting methods which means nurseries are better able to meet grower demand for trees to establish new orchards. Our data demonstrated for the first time in a fully replicated scientific study that mini-grafted trees produce their first commercial crop at the same time as the more expensive traditional-grafted trees. Both mini-grafted and traditional-grafted tree types rely on new shoots from the scion graft to form the trunk of the new tree, regardless of the size of the trunk on the rootstock. This means that both tree types have the same issue of developing a balance between trunk diameter and canopy growth in order to produce a more stable tree with good anchorage that will not blow over in strong winds.

Discussion has also been generated on the use of cutting-grown trees instead of the traditional-grafted seedlings.

Cutting-grown trees are less expensive to produce and do not require two years of growth in the nursery before field planting. Plus, their use may reduce within-orchard variability often associated with trees on seedling rootstocks.

New knowledge has also been generated on growth responses of young macadamia trees to pruning, trunk girdling and plant growth regulators with the objective to increase precocity (time to first commercial harvest) and productivity. Project outcomes will include improved orchard productivity and new options for establishment and management of young orchards, integrated with outcomes from the multi-industry “small trees” programme. Growers spend considerable time in the orchard training, pruning and staking young trees during their establishment phase to increase stability in strong winds. A less aggressive pruning technique was demonstrated and PGR treatments identified that could reduce the number of pruning rounds required during tree establishment and possibly avoid the need for tree staking.

Trunk girdling was demonstrated to be a very effective technique to increase the productivity of young trees and to advance the timing of the first commercial harvest by one year. This is a significant result as it will help growers receive an earlier return on their investment and for the orchard to reach break-even point. The results of our project were so dramatic that a grower in QLD tested the method on a few trees at their orchard. They were sufficiently convinced by the results that they intend to apply the technique across all of the young orchards starting in 2019.

This programme has also improved our understanding of macadamia tree physiology and tree architecture. In particular, our data and observations have stimulated discussion on the possible role of light inhibition of flowering in macadamia which would explain why macadamia trees produce more flowers in the low light environment experienced on the inside of trees canopies rather than on the outside. Apical dominance and suppression of sylleptic shoot growth is another interesting feature of macadamia physiology that presents significant problems for growers. Instead of having a strong fruiting framework with shoots/branches evenly placed along a parent axis, shoot production generally forms in whorls with several branches developing from the same point.

Monitoring and evaluation

This research programme did not have a formal “project reference group”. Project monitoring and evaluation was facilitated through regular contact with the AMS and senior consultants and growers. Project outcomes have been augmented through integration of orchard management systems by regular consultation with the AMS Productivity Development Officer and with members of the multi-industry “small trees” programme. The significant findings have been discussed at regular “on-site” meetings with the collaborating growers in QLD and NSW; with Dr John Wilkie and his team from DAF Queensland; and with senior industry consultants. Data and discussion have also been presented at the annual AMS Consultant Workshops and Annual Conferences and at Hort Innovations macadamia physiology workshop in Bundaberg.

The programme started with a focus on micro-propagated trees, a new technology under development by Kim Wilson and Gray Plantations’ nursery in NSW. With a change of ownership at this nursery, it was necessary to focus more on the mini-grafted trees as the best option for future orchard systems and to move more quickly to establish orchard-based projects. New sites were identified in QLD and NSW, contacts were made with new nurseries to supply the required plants and a new set of project goals was established after discussion with Hort Innovation and the AMS. This flexible and pragmatic project management ensured the continual improvement of the programme and was key to the project moving forward and delivering quality outcomes for Hort Innovation and the Australian macadamia industry.

Working with commercial nurseries and growers places operational constraints on project management that are not encountered on designated research orchards. While this can restrict the scope of activities and experimental treatments that can be applied, working directly with growers and nurseries does ensure there is a strong focus on commercial outcomes which was most certainly the case with this programme. New research directions were identified. The task now is to take these new directions on to develop a new suite of programmes that deliver value to the Australian macadamia industry.

Recommendations

1. Hort Innovation and AMS are encouraged to promote the use of mini-grafted macadamia trees as a cost-effective solution to ensuring easier access to trees for new orchards without compromising yield or time to commercial harvest.
2. Hort Innovation and the AMS are encouraged to support further scientific studies involving trunk girdling to promote flowering and cropping on young macadamia trees. These trials should include a wider range of varieties and growing regions and aim to optimise timing of girdling treatments for each variety/region to ensure optimal outcomes.
3. Hort Innovation and AMS should promote further research and possible product registration for the use of PGRs to inhibit shoot growth in macadamia orchards as a means to reduce pruning and management costs for new orchards.
4. Hort Innovation and AMS should encourage detailed scientific studies on answering the question "why do macadamia trees flower on the inside of tree canopies and not on the outside?" Projects should consider the adaptive significance of this flowering habit and the possibility of light inhibition of flowering with corresponding studies on gene expression.

Refereed scientific publications

Journal article

Howlett, B., Read, S., Alavi, M., Cutting, B., Nelson, W., Goodwin, R., Cross, S., Thorp, T.G., Pattemore, D. 2018. Cross-pollination can enhance macadamia yields, even in the presence of branch-level resource allocation limitations. HortScience (accepted)

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

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Appendices

APPENDIX I	Comparison of micro-grafted, mini-grafted and traditional grafted macadamia trees.
APPENDIX II	Evaluation of plant growth regulator PGR1 on micro-grafted macadamia trees to stimulate branching and development of central leader trees.
APPENDIX III	Evaluation of plant growth regulator PGR2 as a means to stimulate axillary shoot production from dormant "epicormic" buds on the trunks of traditional grafted macadamia trees.
APPENDIX IV	Early tree development of mini-grafted, traditional grafted and cutting grown macadamia trees.
APPENDIX V	Effect of three levels of pruning, removing 50%, 80% and 100% of the canopy, on growth and flowering of young macadamia trees.
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APPENDIX IX	Project activities.

APPENDIX I Comparison of micro-grafted, mini-grafted and traditional grafted macadamia trees

Propagation technique	***Description of technique***	***Expected benefit over other propagation types - Impact on practices; costs implications; expected benefit to growers (levy payers) and broader industry***
Micro-grafting	Micro-grafted tree, small stem diameter (1.5-3 mm) on rootstock and scion, planted in the field 8-12 months from seed and 3 months from grafting Height of tree at planting could be 50-70 cm	• Most difficult technique being developed in related Hort Innovation project • Reduced cost to produce as less time in nursery: expected 55-60% production saving over standard tree and 20% production saving over mini-grafted tree at time of planting • Commensurate reduction in cost to growers: tree cost is a big cost in establishing an orchard • Reduced wait to access planting material: One major problem now is that if a major investor wants to plant out new farms in Australia, they have to wait two years for a reasonable number of trees as no nursery will grow that number speculatively. The micro-grafted trees would reduce that wait time by 50% • Possible quicker time to production than standard tree – to be determined as part of project • Expected to be better option than standard trees for intensive planting systems
Mini-grafting	Mini-grafted tree, small stem (3-6 mm) on rootstock and scion, planted in the field 10-12 months from seed and 3 months from grafting Height of tree at planting could be 70-90 cm	• Relatively easy propagation technique • Moderate cost to produce as less time in nursery; expected 45-50% production saving over standard tree • Commensurate cost reduction to growers: reduced orchard establishment costs • Reduced wait to access planting material: benefit as above • Possible quicker time to production than standard tree – to be determined as part of project • Expected to be better option than standard trees for intensive planting systems
Traditional grafted tree	Industry standard tree from nursery, large stem on rootstock (10-12 mm), medium stem (6-8 mm) on scion, planted in the field 24 months from seed and 3 months from grafting. Height of tree at planting could be 90-120 cm	• Easy to propagate but expensive due to long time spent in nursery • Currently growers paying approx. $16 / tree • Requires heading cut to obtain desired framework in orchard • Slow to come into production (year 4)

APPENDIX II Evaluation of plant growth regulator PGR1 on micro-grafted macadamia trees to stimulate branching and development of central leader trees

Introduction:

Young macadamia trees exhibit very strong apical dominance with almost complete suppression of axillary shoot growth. This makes it difficult to produce trees with a strong fruiting framework and results in considerable expense for growers to prune and train young trees. Other fruit industries, for example apple and avocado, use plant growth regulators (PGRs) to reduce apical dominance and stimulate axillary shoot growth. In this project we evaluated the use of PGR1, a commercially available PGR containing a combination of gibberellins and cytokinin.

Treatments were applied in anticipation of strong extension growth from the terminal bud on each plant, with the potential PGR effect being to stimulate sylleptic axillary shoot growth at each leaf node as the parent growth axis (single trunk) extends. This will produce the desired slender pyramid growth habit desired for high-density plantings.

Materials and methods:

The first PGR1 treatments were applied to small micro-grafted trees in October 2014 once temperatures had started to increase in spring and the first micro-grafted plants were available from the nursery. Initial treatments were designed to screen a range of concentrations and application methods (Table 1). The trees were at various stages of development, some had been taken straight from the plastic propagation house while others had been hardened off in full sunlight.

Tree height was recorded at the time of treatment application and then the number and location of new axillary shoot production recorded post treatment. Following treatment, all plants were grown in the same section of the propagation house with three to five plants per treatment depending upon the availability of micro-grafted plants (Table 2). Statistical analyses were done using Minitab v18 statistical software with mean separation by Tukey-Kramer method, $P \leq 0.05$.

Table 1. Plant material and treatments used to evaluate the use of PGR1 applied as a spray or mixed with acrylic paint, to stimulate axillary shoot growth on young "micro-grafted" macadamia trees.

Plant material			Plant height (cm) when treatments were applied	Status
Project	**Scion**	**Rootstock**		
1	'842'	695	18.4	Plants hardened off in full sunlight
2	'741'	695	16.2	Plants hardened off in full sunlight
3	'A203'	695	11.9	New plants recently removed from propagation house and placed in shade house
4	'842'	H2	12.5	New plants straight from propagation house to shade house for treatment

Treatments			
Control	**PGR1 15 mL/L**	**PGR1 25 mL/L**	**PGR1 paint**
Water + wetter (0.05%)	15 mL/L + wetter (0.05%)	25 mL/L + wetter (0.05%)	25 mL + 75 mL acrylic paint

Results and discussion:

Treatments with PGR1 did not produce the desired sylleptic axillary shoot growth (without a period of dormancy) as the parent shoot/trunk of each plant extended (Table 2, Figure 1). However, PGR1 did on occasion stimulate the growth of subterminal, dormant buds below the main growing point present at the time treatments were applied. In each case this growth response was greatest when PGR1 was applied to the shoot tip mixed with acrylic paint. While it is possible the paint treatments may have damaged the terminal bud, forcing growth of the subterminal buds, this is unlikely as the PGR1 spray treatments had a similar, although smaller effect, as the paint treatment.

Table 2. Axillary shoot production in response to PGR1 treatments applied as a spray or mixed with acrylic paint to stimulate axillary shoot growth on young "micro-grafted" macadamia trees. Four projects were completed using different scion/rootstock combinations. Values are means ± SE. Significance: NS = not significant.

Project	Scion	Rootstock	Treatment	No. of trees	No. of shoots per plant
1	'842'	695	Control	4	1.3 ± 0.5
			PGR1 15 mL/L	5	0.4 ± 0.4
			PGR1 25 mL/L	5	0.6 ± 0.4
			PGR1 paint	5	3.6 ± 0.9
			Significance		NS
2	'741'	695	Control	4	0
			PGR1 15 mL/L	3	1.7 ± 1.2
			PGR1 paint	3	2.7 ± 2.2
			Significance		NS
3	'A203'	695	Control	4	0
			PGR1 15 mL/L	3	0.3 ± 0.3
			PGR1 paint	3	1.7 ± 1.2
			Significance		NS
4	'842'	H2	Control	4	0
			PGR1 15 mL/L	3	0
			PGR1 paint	3	3.0 ± 0
			Significance		-

It was only with the larger plants used in Project 1 that significant numbers of new shoots were produced on control plants (Table 2). Each of these new shoots developed from dormant axillary buds near the base of the plant, just above the graft union (Figure 1).

The desired growth response in this set of projects was for the PGR1 treatments to overcome apical dominance and stimulate axillary shoot growth without an intervening period of dormancy. This did not occur; instead, the treatments stimulated only the growth of dormant, subterminal buds.

These results highlight the very strong apical dominance or lack of branching observed on macadamia trees, which is a major challenge for developing new, more productive growing systems with this crop. The PGR1 treatments we applied to small micro-grafted trees were not able to overcome this strong apical dominance.

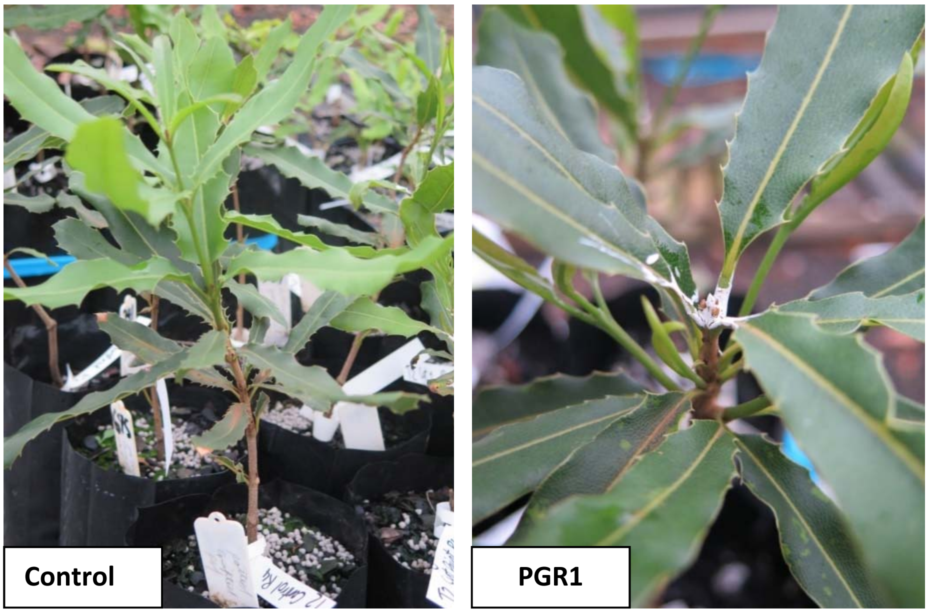


Figure 1. Axillary shoot production in response to PGR1 treatments applied mixed with acrylic paint to stimulate axillary shoot growth on young "micro-grafted" macadamia trees. Control plants (left) produced a single terminal shoot; treated plants (right) stimulated new axillary shoots from previously dormant buds below the main growing point of the plant.

With a change of ownership at the collaborating nursery we were not able to continue working with micro-grafted trees in the nursery and instead shifted our attention to the slightly larger commercially available mini-grafted trees (Appendix I) growing on an orchard near Maryborough in Queensland. Treatments (25 ml/L) were applied on 10 December 2015 to 'A203' and '741' mini-grafted trees on H2 seedling rootstock planted in September 2015. Unfortunately, the treatments caused significant leaf damage without increasing lateral shoot production (data not presented). We did not continue further research with this product.

Rather than developing methods to overcome apical dominance and the suppression of branching, an alternative approach was adopted which was to focus on use of PGR products to force growth from dormant epicormic buds on older wood (refer Appendix III).

APPENDIX III Evaluation of plant growth regulator PGR2 as a means to stimulate axillary shoot production from dormant "epicormic" buds on the trunks of traditional grafted macadamia trees

Introduction:

Projects previously described (Appendix II) using PGR1 to overcome apical dominance and stimulate axillary shoot growth on young micro-grafted macadamia trees were not successful. An alternative approach might be to use another PGR product to stimulate dormant epicormic buds to grow and produce new axillary shoot growth. PGR2 is a product containing thidiazuron used in apple nurseries to stimulate growth of epicormic buds in order to produce shoots for production of clonal rootstocks.

Materials and methods:

Treatments using PGR2 were applied on 18 November 2014 to potted, three-year-old 'A4' mini-grafted macadamia trees on H4 rootstock (Table 1). Treatments were applied with a small paintbrush to an unbranched section of the trunk on each plant, above and below the graft union. Each section comprised a portion of two- and three-year-old wood. For one of the treatments, all leaves were removed from the treated trunks before treatment. This included removal of all leaves up until the first whorl of branches on the upper parts of the trees. These branches had been produced in response to a heading cut made 12 months previously.

Table 1. Treatments using PGR2 applied to the unbranched section of trunk of three-year-old 'A4' mini-grafted macadamia trees on H4 rootstock. Trees were growing in large (50 L) planter bags and had been headed back 12 months prior to treatment to produce several new branches; PGR2 was not applied to these branches.

Treatments (n = 4 trees)		Method of application
Control	Water + 3% mineral oil	PGR2 painted on dormant buds and stems along the trunk of each tree
PGR2 (with leaves)	2500 mg/L + 3% mineral oil	PGR2 painted on dormant buds and stems along the trunk of each tree
PGR2 (no leaves)	2500 mg/L + 3% mineral oil	PGR2 painted on dormant buds and stems along the trunk of each tree with all leaves removed from this section of trunk

We recorded the number of new shoots produced along the trunks of treated trees, including sections above and below the graft union. All trees were growing in the same part of the nursery before and after treatment application, with four replicate trees per treatment. Raw data are presented only, with no statistical analyses, to show the individual tree responses.

Results and discussion:

A strong response was recorded to the PGR2 treatments, often with several new shoots developing from each previously dormant epicormic axillary bud along the treated sections of the trunks, both above and below the graft union (Table 2, Figure 1). In some cases the treatments produced multiple shoots from the same compound axillary bud. However, not all shoots continued development beyond the initial period of growth and these may require follow-up treatment with a growth stimulant to produce full-sized leafy shoots.

Although the PGR2 product was applied only to the sections of trunk above the graft, there was run-off of excess product down the trunk to the rootstock below the graft. This stimulated new shoot growth on the rootstock which was subsequently removed as from a commercial point of view we were more interested in shoots developing from the scion variety than from the rootstock (Table 2).

Table 2. New shoot growth in response to treatments applied on 18 November 2014 using PGR2 applied to the unbranched trunks of potted macadamia trees ('A4' scion cultivar grafted onto H4 rootstock). New shoots developing from the rootstock were removed in December after treatment application.

Treatment	Replicate	No. of shoots below graft (recorded and removed 22 December 2014)	No. of shoots above graft (recorded 1 April 2015)
Control	1	0	0
	2	0	0
	3	0	0
	4	6	0
PGR2 (with leaves)	1	1	1
	2	22	18
	3	12	1
	4	8	3
PGR2 (no leaves)	1	4	1
	2	15	8
	3	0	17
	4	6	30

Figure 1. New axillary shoot production in response to treatments with PGR2 painted onto the stems of young 'A4' macadamia trees.

Although difficult to judge with so few replicates, there was possibly some indication that removal of leaves before treatment had a positive effect on axillary shoot production (Table 2).

Flowering data were to be collected from all trees and shoots in spring 2015 to determine whether the “new” shoots had the same reproductive ability as the existing shoots further up the trees, above the treated sections of each trunk. Unfortunately the trees were discarded before we had the opportunity to do this.

This very positive result with PGR2 to stimulate already-dormant epicormic buds into becoming active and producing new shoot growth will be of interest for growers wanting to stimulate branching and productivity on larger trees. In over-crowded orchards trees often have large, barren, unbranched sections of wood. The traditional response has been to reduce the number of major branches by selective limb pruning to increase the amount of light in the lower canopy zones. Treatments with PGR2 in combination with remedial pruning could significantly increase the rate of new shoot production and thus reduce the time for these trees to return to full productivity post pruning.

APPENDIX IV Early tree development of mini-grafted, traditional grafted and cutting grown macadamia trees

Introduction:

The process of site selection and consultation with industry consultants, growers and nurseries generated wide-ranging discussion on the key issues affecting tree establishment when planting out new macadamia orchards, in particular when using mini-grafted trees. One point of concern was that the mini-grafted trees took too long to develop a sufficiently strong, robust trunk for the trees to be free-standing without a stake. Growers generally respond to this by applying several heading cuts in the hope that this will aid stem thickening. This practice, in turn, makes the trees top-heavy and thus less stable in strong winds. If heading cuts are not applied then the new shoot growth tends to bend over and in some cultivars, for example 'A203', new growth develops from the bend on these shoots.

Another opportunity to produce a stronger more stable plant as an alternative to mini-grafted trees is to use "small" cutting-grown plants. Use of clonal rootstocks grown from own-rooted cuttings has become routine in South African macadamia orchards. It is important for Australian growers to have good data on the performance of cutting-grown trees in Australian conditions if this method of propagation is going to be widely adopted here.

In this project, we compared tree growth and performance of mini-grafted and traditional grafted trees on seedling rootstock, and two sizes of clonal trees propagated from own-rooted cuttings.

Materials and methods:

Three tree types were compared at a commercial orchard near Maryborough, QLD:

1. **Mini-grafted trees:** 'A16', 'A203' and '741' on H2 seedling rootstock; supplied by Forrest Nurseries near Bundaberg QLD
2. **Traditional grafted trees:** 'A203' and '741' on H2 seedling rootstocks supplied by Ray Norris at Alloway Macadamia near Bundaberg.
3. **Cutting-grown trees:** Two size grades (in 50 ml and 90 ml containers) of 'A203' and '741' plants propagated from rooted cuttings, supplied by David Bell at Hidden Valley Plantations at Beerwah QLD.

All traditional, mini-grafted and large cutting-grown trees were pruned soon after planting in October 2015 to remove any side shoots along the trunk up to a height of approximately 60 cm. Small cutting-grown trees were not available for planting until November 2015, with some replants added in March 2016. Traditional grafted trees were larger than the other tree types and required additional pruning using the standard practice employed at this orchard. This involved cutting back shoots to remove up to 80% of the leaf canopy but leaving a dominant shoot in the south-east (SE) corner which is the direction for the prevailing wind at this site. This pruning was repeated in March and June 2016 as the trees still had too much canopy growth compared with the diameter of the trunks. The mini-grafted and large cutting-grown trees were pruned only once in June 2016.

Tree height, trunk diameter below and above the graft were recorded at intervals during the season. At planting, trunk diameter was measured below the graft, as at this stage there was no distinct trunk developed from the graft. Macadamia trees are grafted with a scion approximately 8-10 cm long and several shoots are allowed to develop from each scion. The number of shoots from the graft is reduced as the tree grows so that the most dominant one is retained to ultimately become the trunk of the mature tree. Trunk diameter was measured above the graft, at approximately 60 cm high, once this dominant trunk had developed.

Mini-grafted trees
('A203' on left and '741' on right)

Traditional grafted tree ('741')

Rooted cutting, small (50ml) container
('A203')

Rooted cutting, large (90ml) container
('A203')

Figure 2. Range of tree types planted in the macadamia field trial near Maryborough, Queensland.

Tree canopy volume was determined from digital images taken at right angles to each tree along the row. ImageJ Fiji software (http://imagej.nih.gov/ij) was then used to trace the perimeter of the tree canopy from which to calculate cross-sectional canopy area. This cross-sectional area was then converted to a circle from which it was possible to calculate radius. Canopy volume (V) was calculated as $V = 4/3*\pi*radius^3$. All trees were isolated and not growing into each other so it was valid to assume a uniform canopy cross-section regardless of the angle at which the digital image was taken.

The number of racemes were counted in spring 2017, the first year of flowering, and in 2018. Trees were hand harvested in March 2018 and the total weight of fruit recorded. We did not have resources available to determine crack out data (% of nut in shell) for each treatment so data are presented as total yield including hull + shell + kernel. To provide some indication of crack out values we took a combined sample from each of the projects and removed the hulls for weighing. These data showed the 'A203' nuts comprised 45% hull and 55% nut in shell.

The four treatments were applied to 14 replicate trees per treatment across two adjacent rows (28 trees per row) in a systematic design with treated trees alternating along each row. Statistical analyses were done using Minitab v18 statistical software with mean separation by Tukey-Kramer method, $P \leq 0.05$.

Results and discussion:

Average trunk diameter and tree height of the traditional grafted trees at planting were nearly twice as large as those on the mini-grafted and large cutting-grown trees planted at the same time in October 2015 (Table 1). By March 2016, trunk diameter on the traditional grafted trees had shown only minimal increase; tree height was relatively unchanged as trees had been pruned before measurement. For the mini-grafted and large cutting-grown trees there had also been little increase in trunk diameter but tree height had almost doubled. For example, the mini-grafted 'A203' trees had increased by 81% from 42 to 76 cm tall but trunk diameter had increased only by 8% from 6.1 to 6.6 mm. These data clearly highlight the issue of slow increase in trunk diameter compared to rapid canopy growth.

While the mini-grafted trees were still smaller than the traditional grafted trees in March 2016, by October 2016 the mini-grafted trees had caught up and both tree types had similar canopy height and trunk diameter (Table 1, Figure 1). Note that the diameter of the trunk below the graft on the traditional grafted trees was still larger than the trunk on the mini-grafted trees (data not shown), however, this section of trunk does not form the main trunk of the tree as this develops above the graft. It is this section of trunk above the graft that is important for the stability of the tree.

In September 2018, tree canopy volume was similar across all 'A203' tree types. However, cutting-grown '741' trees were smaller than either the mini-grafted or traditional-grafted trees (Table 2, Figure 1).

Several of the smaller cutting-grown trees did not survive during this first year of growth. This was a commercial site and all trees, regardless of size, received the same management and irrigation programme. It is likely that these relatively small cutting-grown trees received too much water during this early stage of their growth and that this contributed to their demise.

Table 1. Increase in trunk diameter and height of macadamia trees during their first year of growth after planting in field trials at Maryborough, Queensland. Trunk diameters were measured at the base of the trees, below the graft, soon after planting and then above the graft, at approximately 60 cm above the ground, once a dominant trunk had developed from the graft. Cutting-grown trees were measured at approximately midway along the trunk. Traditional grafted trees were pruned in March 2016, before tree dimensions were measured. All trees were pruned again in June 2016. Values are mean ± SE (n = 14 trees per treatment). Values in each column for each cultivar followed by the same lower-case letters were not significantly different. Significance: NS = not significant; * = *P*<0.05; ** = *P*<0.01; * = *P*<0.001.**

Cultivar	Rootstock	Tree type	Planted	Tree size					
				(at planting)		22 March 2016		11 October 2016	
				Trunk diameter[1] (mm)	Tree height (cm)	Trunk diameter[2] (mm)	Tree height (cm)	Trunk diameter[2] (mm)	Tree height (cm)
'A203'	H2	Mini-graft	7/10/2015	6.1 ± 0.3 b	42 ± 1.3 b	6.6 ± 0.4 b	76 ± 0.9 b	14.1 ± 0.7 a	125 ± 2.5 ab
	H2	Traditional grafted	8/10/2015	11.1 ± 0.4 a	105 ± 3.1 a	9.5 ± 0.5 a	93 ± 2.3 a	13.9 ± 0.6 ab	133 ± 3.4 a
	'A203'	Small cutting (50 mm tubes)	17/11/2015[3]	3.5 ± 0.1 c	20 ± 2.4 c	3.9 ± 0.2 c	43 ± 5.4 c	10.9 ± 0.8 b	111 ± 4.7 c
	'A203'	Large cutting (90 mm tubes)	7/10/2015	5.2 ± 0.2 b	37 ± 1.2 b	5.9 ± 0.4 b	74 ± 1.1 b	12.2 ± 0.8 ab	113 ± 2.7 bc
			Significance	***	***	***	***	*	***
'741'	H2	Mini-graft	7/10/2015	7.0 ± 0.3 b	37 ± 1.1 b	7.0 ± 0.5 b	74 ± 1.4 ab	14.1 ± 0.4 a	122 ± 2.7 a
	H2	Traditional grafted	8/10/2015	13.2 ± 0.7 a	102 ± 2.2 a	13.1 ± 0.4 a	83 ± 2.1 a	15.4 ± 0.6 a	132 ± 6.6 a
	'741'	Small cutting (50 mm tubes)	15/03/2016	2.8 ± 0.1 c	7.2 ± 0.9 c	2.8 ± 0.1 c	7.2 ± 0.9 c	nd[4]	nd
	'741'	Large cutting (90 mm tubes)	7/10/2015	6.1 ± 0.5 b	43 ± 5.0 b	5.8 ± 0.3 b	68 ± 3.9 b	9.2 ± 0.7 b	103 ± 4.7 b
			Significance	***	***	***	***	***	**

[1] Measured below the graft union for grafted plants and mid-way along the trunk for cutting-grown plants

[2] Measured above the graft union and/or approximately 60 cm above the ground for grafted and cutting-grown plants

[3] Replacement trees planted 15 March 2016

[4] No data as several trees did not survive

‘A203’ Mini-graft	Traditional graft	Large cutting (90 mm tubes)

‘741’ Mini-graft	Traditional graft	Large cutting (90 mm tubes)

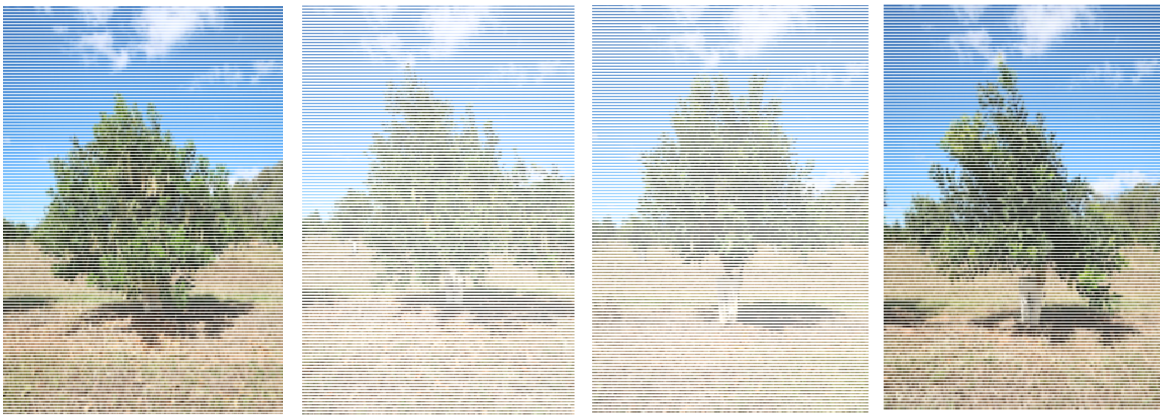
Figure 1. Comparison of mini-grafted, traditional-grafted and cutting-grown ‘A203’ and ‘741’ macadamia trees planted in October 2015 at Maryborough, Queensland. Images were taken in October 2016.

In summary, it would seem that after one season’s growth, the mini-grafted trees had reached the same stage of canopy development as the traditional grafted trees but with less cost in terms of initial tree cost and pruning costs. We did not collect any data on root system development for these trees and, of course, the true test of performance of each tree type is how long trees take to produce their first commercial crop.

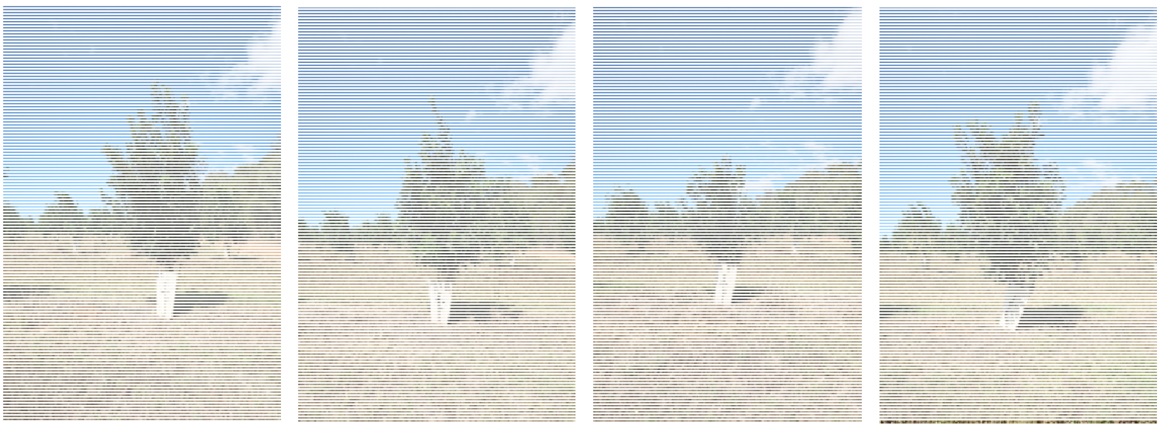
Table 2. Trunk diameter, height and canopy volume of ‘A203’ and ‘741’ macadamia trees at Maryborough, Queensland (QLD) in September 2018. Trees were planted in October 2015. Values are mean ± SE (n = 14 trees per treatment). Values in each column for each cultivar followed by the same lower-case letters were not significantly different. Significance: NS = not significant; * = *P*<0.05; ** = *P*<0.01; * = *P*<0.001.**

Cultivar	Rootstock	Tree type	Trunk diameter (mm)	Tree height (m)	Canopy volume (m^3)
A203	H2	Mini-graft	61 ± 1.4 ab	3.4 ± 0.13	11.5 ± 1.0
	H2	Traditional grafted	66 ± 2.1 a	3.3 ± 0.15	9.0 ± 0.9
	A203	Small cutting (50 mm tubes)	57 ± 2.5 b	3.4 ± 0.26	11.7 ± 2.3
	A203	Large cutting (90 mm tubes)	60 ± 1.3 ab	3.3 ± 0.15	11.8 ± 1.3
		Significance	*	NS	NS
741	H2	Mini-graft	65 ± 1.5 a	3.2 ± 0.10 a	5.3 ± 0.4 a
	H2	Traditional grafted	66 ± 2.3 a	3.3 ± 0.15 a	4.6 ± 0.6 a
	741	Small cutting (50 mm tubes)	nd[1]	nd	nd
	741	Large cutting (90 mm tubes)	49 ± 3.1 b	2.7 ± 0.13 b	2.7 ± 0.4 b
		Significance	***	***	**

[1] nd = no data as several tress did not survive



‘A203’ Mini-graft **‘Traditional graft** **Small cutting** **Large cutting**



‘741’ Mini-graft **‘Traditional graft** **Small cutting** **Large cutting**

Figure 2. Comparison of mini-grafted, traditional-grafted and cutting grown ‘A203’ and ‘741’ macadamia trees planted in October 2015 at Maryborough, Queensland (QLD). Images were taken in September 2018.

The first flowering data were recorded from the ‘A203’ trees in September 2017 and fruit yields were collected in March 2018. These data indicated no difference in the number of racemes or the amount of crop on the mini-grafted, traditional grafted and large cutting grown trees (Table 3). Note that there were no racemes or crop produced on the ‘741’ trees in this trial in the 2017/18 season.

Table 3. Number of racemes in spring 2017 and yield (fresh weight of hull + shell + kernel) in March 2018 on mini-grafted, traditional-grafted and cutting-grown ‘A203’ macadamia trees planted in October 2015 in Maryborough, Queensland. Values are mean ± SE (n = 14 trees per treatment). Significance: NS = Not significant.

Cultivar	Rootstock	Tree type	No. of racemes	Yield[1] (g/tree)
			Sept. 2017	**March 2018**
‘A203’	H2	Mini-graft	25 ± 10	95 ± 0.04
	H2	Traditional-grafted	20 ± 13	53 ± 0.03
	‘A203’	Cutting-grown (90 mm tubes)	25 ± 7	59 ± 0.02
	‘A203’	Cutting-grown (50 mm tubes)	nd[2]	nd
		Significance	*NS*	*NS*

[1] Yield = hull + shell + kernel; estimated 55 % nut in shell from combined subsample
[2] no data as several trees did not survive

There were too many flowers on the ‘A203’ trees in spring 2017 to get an accurate count of the number of racemes. However, we were able to do this on the ‘741’ trees which were flowering for the first time. These data showed similar numbers of racemes on the mini-grafted, traditional-grafted and large cutting grown trees (Table 4).

Table 4. Number of racemes in spring 2018 on mini-grafted, traditional-grafted and cutting-grown ‘741’ macadamia trees planted in October 2015 in Maryborough, Queensland. Values are mean ± SE (n = 14 trees per treatment). Significance: NS = not significant.

Cultivar	Rootstock	Tree type	No. of racemes
			Sept. 2018
‘741’	H2	Mini-graft	35 ± 8
	H2	Traditional-grafted	26 ± 14
	‘741’	Cutting-grown (90 mm tubes)	19 ± 16
	‘741’	Cutting-grown (50 mm tubes)	nd[1]
		Significance	*NS*

[1] no data as several trees did not survive

APPENDIX V Effect of three levels of pruning, removing 50%, 80% and 100% of the canopy, on growth and flowering of young macadamia trees

Introduction:

It is current practice for macadamia growers to implement a pruning strategy during the establishment phase of their orchards to produce trees that have a better balance between trunk diameter and canopy growth. This is to make sure that the trees have good anchorage and can withstand strong winds without being blown over. The standard method involves cutting back shoots to remove up to 80% of the leaf canopy but leaving a dominant shoot in the south-east (SE) corner or the windward side of trees. This pruning is repeated at least twice during the first summer and once in the following summer before trees produce their first flowers. In this project we made a comparison of different pruning methods for young trees to find a better solution in terms of growth management and that was easier and more cost effective to apply.

Materials and methods:

Three pruning treatments were applied to mini-grafted 'A203' trees growing on H2 seedling rootstock at Maryborough Queensland. The trees were planted in February 2015 and the following treatments were applied on 11 December 2015:

1. Industry standard pruning (control) with up to 80% of canopy removed but leaving a single strong shoot in SE corner (direction of prevailing wind)
2. All shoots cut back by 50%, but leaving a single strong shoot in SE corner (direction of prevailing wind)
3. Trunks cut back to 60 cm (heading cut) leaving no side branches and thus removing 100% of the leaf canopy; trunks painted white with dilute acrylic paint to prevent sun damage.

Tree height and trunk diameter above the graft, at approximately 60 cm high, were recorded at intervals during the season. Tree canopy volume was determined from digital images taken at right angles to each tree along the row. ImageJ Fiji software (http://imagej.nih.gov/ij) was then used to trace the perimeter of the tree canopy from which to calculate cross-sectional canopy area. This cross-sectional area was then converted to a circle from which it was possible to calculate radius. Canopy volume (V) was calculated as $V = 4/3*\pi*radius^3$. All trees were isolated and not growing into each other so it was valid to assume a uniform canopy cross-section regardless of the angle at which the digital image was taken.

The number of racemes were counted in spring 2017, the first year of flowering, and 2018. Trees were hand harvested in March 2018 and the total weight of fruit recorded. We did not have resources available to determine crack out data for each treatment so data are presented as total yield including hull + shell + kernel. To provide some indication of crack out values for each cultivar, we took a combined sample from each of the projects and removed the hulls for weighing. These data showed the 'A203' nuts comprised 45% hull and 55% nut in shell.

The three treatments were applied to 14 replicate trees per treatment across two adjacent rows (21 trees per row) in a systematic design with treated trees alternating along each row. Statistical analyses were done using Minitab v18 statistical software with mean separation by Tukey-Kramer method, $P \leq 0.05$.

Table 1. **Trunk diameter and tree height of 'A203' macadamia trees in response to pruning treatments to remove 50%, 80% and 100% of the leaf canopy from each tree. The trees were planted at Maryborough QLD in February 2015 and pruning treatments applied on 11 December 2015. The "control" treatment trees were pruned again in March and June 2016 and the 50% pruning treatment trees were pruned again in June 2016. Values are mean ± SE (n = 14 trees per treatment). Values in each column followed by the same lower-case letters were not significantly different. Significance: NS = not significant; ** = *P*<0.01; *** = *P*<0.001.**

		Tree size					
Pruning treatment	**Leaf canopy removed**	**Trunk diameter (mm)**	**Tree height (cm)**	**Trunk diameter (mm)**	**Tree height (cm)**	**Trunk diameter[2] (mm)**	**Tree height (cm)**
		11 December 2015		**22 March 2016**		**11 October 2016**	
Shoots cut back 50%	50%	11.4 ± 0.6	100 ± 2.1 b	15.1 ± 0.5 ab	127 ± 2.9 a	25.9 ± 0.5 a	164 ± 2.1 a
Control (orchard standard)	80%	11.7 ± 0.5	129 ± 2.1 a	16.2 ± 0.5 a	127 ± 3.6 a	25.4 ± 0.7 a	165 ± 3.2 a
Trunk cut back to 60 cm	100%	12.4 ± 0.5	66 ± 0.6 c	13.9 ± 0.4 b	104 ± 3.1 b	24.7 ± 0.7 a	153 ± 2.1 b
	Significance	NS	***	**	***	NS	**

Table 2. **Trunk diameter, height and canopy volume of 'A203' macadamia trees in September 2018 in response to pruning treatments to remove 50%, 80% and 100% of the leaf canopy from each tree. The trees were planted at Maryborough QLD in February 2015 and pruning treatments applied on 11 December 2015. The "control" treatment trees were pruned again in March and June 2016 and the 50% pruning treatment trees were pruned again in June 2016 to remove dominant side shoots. Values are mean ± SE (n = 14 trees per treatment). Significance: NS = not significant.**

Pruning treatment	**Leaf canopy removed**	**Trunk diameter (mm)**	**Tree height (m)**	**Canopy volume (m^3)**
Shoots cut back 50%	50%	70 ±1.5	4.3 ± 0.14	23 ± 2.0
Control (orchard standard)	80%	70 ±1.2	4.2 ± 0.11	21 ± 2.2
Trunk cut back to 60 cm	100%	71 ±1.4	4.4 ± 0.07	26 ± 2.0
	Significance	NS	NS	NS

Results and discussion:

Although the 50% pruning treatment was less severe than the control "orchard standard" pruning that removed up to 80% of the leaf canopy, once the treatments had been applied, the 80% treatment trees were taller than the 50% pruned trees (Table 1, Figure 1). By March 2016 both sets of trees had similar trunk diameters and tree height (Table 1), as the control trees were pruned again on 15 March 2016 to remove excessively large shoots starting to dominate the main trunk. These trees required a similar round of pruning again in June 2016. The 50% pruned trees required only one round of this remedial pruning which was completed in June 2016.

The most severe pruning treatment involved heading back the trunks on these small trees to 60 cm and thus removing all lateral shoots and leaf canopy. These trees were slower to develop over summer so that by March 2016 average trunk diameter and tree height were reduced compared with the other two treatments (Table 1). However, these trees did recover strongly over winter and by October 2016 all sets of trees had similar trunk diameters. Tree height was slightly reduced on the severe "heading back" treatment, but this difference was relatively small and probably not important (Figure 1). By October 2016, the "heading back" treatment trees had required no further pruning. By September 2018, trunk diameter, tree height and canopy volume were similar across all pruning treatments (Table 2).

50% canopy removed | **80% canopy removed (control)** | **100% canopy removed (heading cut)**

Figure 1. Macadamia ('A203') tree growth in response to pruning treatments to remove 50%, 80% and 100% of the leaf canopy from each tree. The trees were planted in Maryborough, Queensland in February 2015 and treatments applied on 11 December 2015. Images were taken in October 2016. The "control" treatment trees were pruned again in March and June 2016 and the 50% pruning treatment trees were pruned again in June 2016 to remove dominant side shoots.

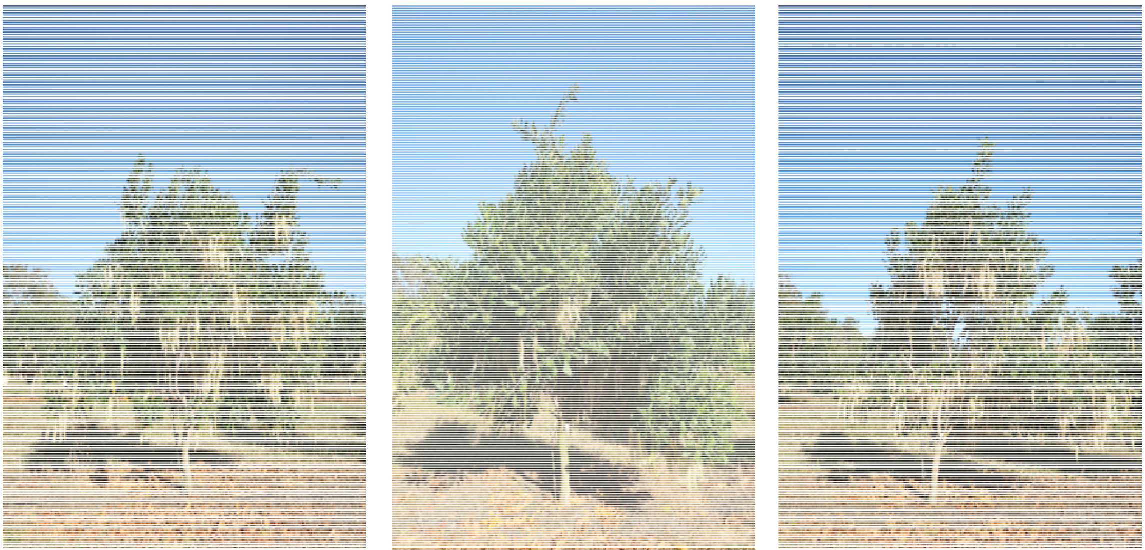
The first flowering data were recorded from these trees in September 2017 and yield data collected in March 2018. There was a trend (P = 0.106) for fewer racemes on the 100% pruning treatment (heading cut) than either the 50% or 80% pruning treatments (Table 3). Although neither of these trends were statistically significant, yield also tended to be higher (P = 0.106) on the 50% pruning treatment trees than on either the 80% or 100% pruning treatment trees.

Table 3. Number of racemes in spring 2017 and yield harvested in March 2018 on 'A203' macadamia trees planted in February 2015 in Maryborough, Queensland. Trees had been pruned on 12 October 2015 removing either 50, 80 or 100% of the leaf canopy. Values are mean ± SE (n = 14 trees per treatment). Significance: NS = not significant.

Pruning treatment	**Leaf canopy removed**	**No. of racemes October 2017 (per tree)**	**Yield[1] March 2018 (kg/tree)**
Shoots cut back 50%	50%	142 ± 22	2.65 ± 0.4
Control (orchard standard)	80%	125 ± 27	1.69 ± 0.4
Trunk cut back to 60 cm	100%	75 ± 17	1.54 ± 0.4
	Significance	*NS*	*NS*
	P =	*0.106*	*0.106*

[1] Yield = hull + shell + kernel; estimated 55% nut in shell from combined subsample

It was not feasible to count the number of racemes on these trees in spring 2018 as there were too many racemes to get an accurate count (Figure 2). Instead an informal rating system was used to record low, medium and high levels of flowering on these trees. These observational data did not reveal any treatment effect on flowering. The first commercial "machine" harvest for these trees will be in March/April 2019.



50% canopy removed | **80% canopy removed (control)** | **100% canopy removed (heading cut)**

Figure 2. Macadamia ('A203') tree growth in response to pruning treatments to remove 50%, 80% and 100% of the leaf canopy from each tree at planting. The trees were planted in Maryborough, Queensland in February 2015 and treatments applied on 11 December 2015. Images were taken in September 2016. Note the cluster of scaffold branches formed at the top of the pruned trunk on the "heading back" treatment.

Overall we believe that the 50% pruning treatment is the better option for growers with mini-grafted trees. The more severe “orchard standard” pruning treatment was probably too severe and required additional maintenance pruning with no net gain in productivity from these young trees. The “heading back” treatment was also severe as it set back the trees in terms of early trunk development, although this was soon overcome. However, this pruning method could have long-term negative effects in terms of scaffold development and ongoing management costs. This is because the “heading back” treatment produced a cluster of new shoots at the top of the pruned trunk (Figure 2). This will create problems with narrow crutch angles and limb breakages unless additional pruning is undertaken to thin out these shoots and ensure future scaffold branches are more widely spaced along the trunk.

APPENDIX VI Evaluation of tree training techniques to promote vigorous growth from epicormic buds to stimulate branching and development of central leader macadamia trees

Introduction:

Modern trends in fruit growing have seen the development of more intensive growing systems to produce sustainable improvements in both fruit yield and quality and thus grower profits. An important strategy is to plant more trees per hectare to increase yields from young orchards and reduce the time taken for orchards to reach break-even point. The development of central leader trees is an important part of this process as the slender pyramid tree shape obtained with central leader trees is more efficient at harvesting sunlight and converting this into economic yield. In some tree crops (including avocado), a stronger trunk can be produced if the original trunk is bent over and pinned down and a new trunk forced to develop from a dormant epicormic bud on the bend of the original trunk. This produces a vigorous new shoot by a process called reiteration that quickly develops into a strong central leader tree. In this preliminary project we evaluated this training technique with macadamia.

Materials and methods:

A trial was established at an orchard near Maryborough QLD in September 2015 using newly planted mini-grafted 'A203' and 'A16' trees. The training treatment involved bending and pinning down the trunk of the trees soon after they were planted in the field (Figure 1). Untreated "control" trees were managed as per standard practice for the orchard. Spray guards had to be removed from the treated trees so weed matting was installed to help control weed growth. An additional treatment was included whereby PGR2 (1250 mg/L + 3% mineral oil) was painted onto the bend in the trunk at the point where epicormic growth was to be stimulated. PGR2 is a product containing thidiazuron that is used in apple nurseries to stimulate growth of epicormic buds in order to produce shoots for production of clonal rootstocks.

Once new epicormic shoots had developed, these were thinned to retain the most dominant and best-positioned shoot to become the trunk of the new tree. Once this new trunk had developed and was growing strongly, the remaining section of the original plant that had been pinned down was removed (Figure 2).

Records were taken of the development of this new trunk including tree height and trunk diameter. Three trees were allocated to each treatment and control for each cultivar (nine trees per cultivar) in a systematic design with treatments alternating along the row and with the two cultivars in adjacent rows. Statistical analyses were done using Minitab v18 statistical software with mean separation by Tukey-Kramer method, $P \leq 0.05$.

Figure 1. Mini-grafted ‘A203’ trees with shroud removed showing weak stem development (left). Trees were pinned down (right) to stimulate stronger shoot/trunk development from epicormic buds along the bend. Weed matting was used for weed control instead of herbicides. Trees were planted in February 2015, images were taken at the time of treatment application in October 2015.

Figure 2. Mini-grafted ‘A203’ macadamia tree growth in response to bending/pinning treatment. Trees were planted in February 2015 and treatments applied in October 2015. New epicormic shoots developed quickly and in February 2016 these were thinned to retain the most dominant and best positioned shoot to become the trunk of the new tree. Images were taken in June 2016 to show epicormic shoot growth before (left) and after (right) thinning. Note the absence of axillary shoot growth on the selected epicormic shoot.

Results and discussion:

All trees responded quickly to the bending/pinning treatments, producing new shoots within 4 weeks of treatment (Figure 2). Application of PGR2 to the dormant buds appeared to accelerate this process (no data). However, the epicormic shoots selected to form the new trunk of each tree were still considerably smaller after 8 months than the diameter of the original trunks on the control trees, regardless of PGR2 application (Table 1, Figure 3). Also, none of these new epicormic shoots produced any axillary shoots (by syllepsis) during the initial growth phase of the epicormic shoot; all were single unbranched stems. This was an unexpected result because in our previous research with avocado this technique produced new and stronger trunks with several side branches. It was not until the growth of the epicormic shoot had ceased that axillary shoots developed (by prolepsis) from resting subterminal buds to produce a whorl of branches characteristic of macadamia.

Table 1. Macadamia ('A203' and 'A16') tree growth (trunk diameter and tree height) in response to bending/pinning treatments with and without use of PGR2. Trees were planted at Maryborough in February 2015 and treatments applied on 12 October 2015. Data were recorded after pruning to a single trunk. Values are mean ± SE (n = 3 trees per treatment). Values in each column followed by the same lower-case letters were not significantly different. Significance: NS = not significant; * = *P*<0.05; ** = *P*<0.01; * = *P*<0.001.**

Cultivar	Treatment	Trunk diameter (mm)	Tree height (m)	Trunk diameter (mm)	Tree height (m)
		15 March 2016		5 June 2016	
'A203'	Control (orchard standard)	12.2 ± 1.0 a	119 ± 3 a	21.1 ± 0.4 a	162 ± 6 a
	Bending/pinning	7.8 ± 0.5 b	83 ± 2 b	12.6 ± 0.7 b	124 ± 7 b
	Bending/pinning+ PGR2	5.3 ± 0.4 b	70 ± 8 b	10.9 ± 1.1 b	120 ± 2 b
	Significance	***	**	***	**
'A16'	Control (orchard standard)	16.3 ± 0.4 a	136 ± 7 a	18.1 ± 1.1 a	145 ± 10 a
	Bending/pinning	6.2 ± 1.2 b	82 ± 15 b	13.3 ± 1.0 b	116 ± 3 ab
	Bending/pinning+ PGR2	6.3 ± 0.8 b	79 ± 4 b	11.6 ± 0.6 b	107 ± 7 b
	Significance	***	**	**	*

Control (orchard standard) **Bending/pinning** **Bending/pinning + PGR2**

Figure 3. 'A203' macadamia tree growth in response to bending/pinning and treatment with PGR2. Trees were planted in February 2015 and treatments applied in October 2015. Images were taken in June 2016.

In my experience I have yet to observe sylleptic shoot growth on macadamia. The inherent branching pattern for macadamia appears to be a result of the terminal bud on the parent axis becoming checked with subterminal buds immediately below this terminal bud producing new shoots to give a whorl of branches. It is this feature which makes it especially difficult to produce a central leader macadamia tree.

APPENDIX VII Use of plant growth regulator PGR3 to inhibit shoot growth and thus avoid pruning costs on one- and two-year-old macadamia trees

Introduction:

Consultation with industry consultants, growers and nurseries generated wide-ranging discussion on the key issues affecting tree establishment when planting out new macadamia orchards, in particular when using mini-grafted trees. One point of concern was that the mini-grafted trees took too long to develop a sufficiently strong, robust trunk for the trees to be free-standing without a stake. Growers generally respond to this by applying several heading cuts in the hope that this will aid stem thickening. This practice, in turn, makes the trees top-heavy and thus less stable in strong winds which necessitates further rounds of pruning. In this project we evaluate the use of PGR3, a widely used triazole plant growth inhibitor, to reduce shoot extension growth and thus reduce pruning costs during orchard establishment.

Materials and methods:

A preliminary trial (Project 1) was set up on 21 December 2015 using PGR3 to inhibit shoot growth. The product was applied at the label rate (1.0%) to ‘A203’ and ‘741’ mini-grafted trees (n = 14 trees) on H2 seedling rootstock planted in September 2015 (Table 1).

A second round of sprays (Project 2) was applied starting in June 2016 using ‘A203’ and ‘741’ mini-grafted trees (n = 14 trees) on H2 seedling rootstock planted in September 2015 (Table 2). Trees sprayed in December 2015 at the 1.0% rate (Project 1) were sprayed a second time in June 2016 with a lower rate (0.5%), while separate sets of trees received their first spray in June and October 2016, also at the lower rate of 0.5%.

A third experiment (Project 3) was set up on slightly older ‘A203’ and ‘A16’ trees (n = 7 trees) mini-grafted with H2 seedling rootstock and planted in February 2015 to compare the effect of PGR3 applied at full label rate (1.0%) and at half label rate (0.5%).

Tree height, trunk diameter above the graft (approximately 60 cm high) and canopy volume were recorded at intervals during the season. Tree canopy volume was determined from digital images taken at right angles to each tree along the row. ImageJ Fiji software (http://imagej.nih.gov/ij) was then used to trace the perimeter of the tree canopy from which to calculate cross-sectional canopy area. This cross-sectional area was then converted to a circle from which it was possible to calculate radius. Canopy volume (V) was calculated as V = 4/3*π*radius3. All trees were isolated and not growing into each other so it was valid to assume a uniform canopy cross-section regardless of the angle at which the digital image was taken.

The number of racemes were counted in spring 2017, the first year of flowering, and in 2018. Trees were hand harvested in March 2018 and the total weight of fruit recorded. We did not have resources available to determine crack out data for each treatment so data are presented as total yield including hull + shell + kernel. To provide some indication of crack out values, we took a combined sample from each of the projects and removed the hulls for weighing. These data showed the ‘A203’ nuts comprised 45% hull and 55% nut in shell. No fruit set on the ‘741’ trees in the 2017/18 season.

All treatments were applied in a systematic design with 7 or 14 trees per treatment (as indicated) alternating along two adjacent rows in the same orchard block. Statistical analyses were done using Minitab v18 statistical software with mean separation by Tukey-Kramer method, $P \le 0.05$.

Raceme counts and tree yield data containing several zero data points were analysed using transformed data based on square root transformations and back-transformed to the original units for presentation.

Results and discussion:

Project 1. 'A203' and '741', PGR3 applied at full rate (1.0%)

The PGR sprays did not affect trunk diameter of either cultivar (Table 1). However, they did inhibit shoot extension growth, especially on the '741' trees in which tree height was 20% less than controls after 3 months (Table 1). 'A203' trees sprayed with PGR3 also tended to be smaller than control trees 3 months after application, although this effect was not significant ($P = 0.192$). The magnitude of the response varied according to the stage of shoot growth when the sprays were applied. A stronger effect was noted on trees that had young actively growing shoots compared to trees where new shoots had stopped extension growth.

Table 1. Effect of PGR3 sprays on growth (trunk diameter and tree height) of mini-grafted A203 and 741 macadamia trees. Trees were planted at Maryborough in September 2015 and PGR treatments applied at label rate (1.0%) on 21 December 2015. Values are mean ± SE (n = 14 trees per treatment). Values in each column followed by the same lower-case letters were not significantly different. Significance: NS = Not Significant; ** = P<0.01.

Cultivar	Treatment	Trunk diameter (mm)	Tree height (cm)	Trunk diameter (mm)	Tree height (cm)
		21 December 2015		15 March 2016	
'A203'	Control	6.3 ± 0.5	30 ± 0.5	7.8 ± 0.5	104 ± 5.3
	PGR3 (1.0%)	6.6 ± 0.2	32 ± 3.5	8.0 ± 0.4	94 ± 5.2
	Significance	NS	NS	NS	NS
'741'	Control	7.7 ± 0.3	41 ± 2.8	9.0 ± 0.6	103 ± 4.6 a
	PGR3 (1.0%)	7.4 ± 0.5	39 ± 2.9	9.0 ± 0.6	83 ± 4.8 b
	Significance	NS	NS	NS	**

Project 2. 'A203' and '741', PGR3 applied at full and/or half rate (1.0% and/or 0.5%)

In October 2016, 4 months after treatment application, the trees in both PGR treatments were 20% shorter than control trees (Table 2, Figure 1). Trees sprayed with PGR3 in December 2015 and again in June 2016 did not require pruning, while the control trees and the June-sprayed trees were pruned once in June 2016. With '741' we consistently reduced tree height by up to 60%, from 152 to 108 cm, but trunk diameter was also reduced by 21%, from 20.4 to 16.1 mm for control and PGR3 #2 treatments respectively. Similar results were found with 'A203' but the effect on trunk diameter was less than with '741'.

By September 2018, average trunk diameter was similar for all treatment with 'A203' trees. However, there was a trend ($P<0.10$) for trunk diameter to be smaller on the PGR treated '741' trees than the controls (Table 3). A similar result was recorded for canopy volume in September 2018 with treated trees tending to be smaller than control trees, although tree height was similar across all treatments for each cultivar.

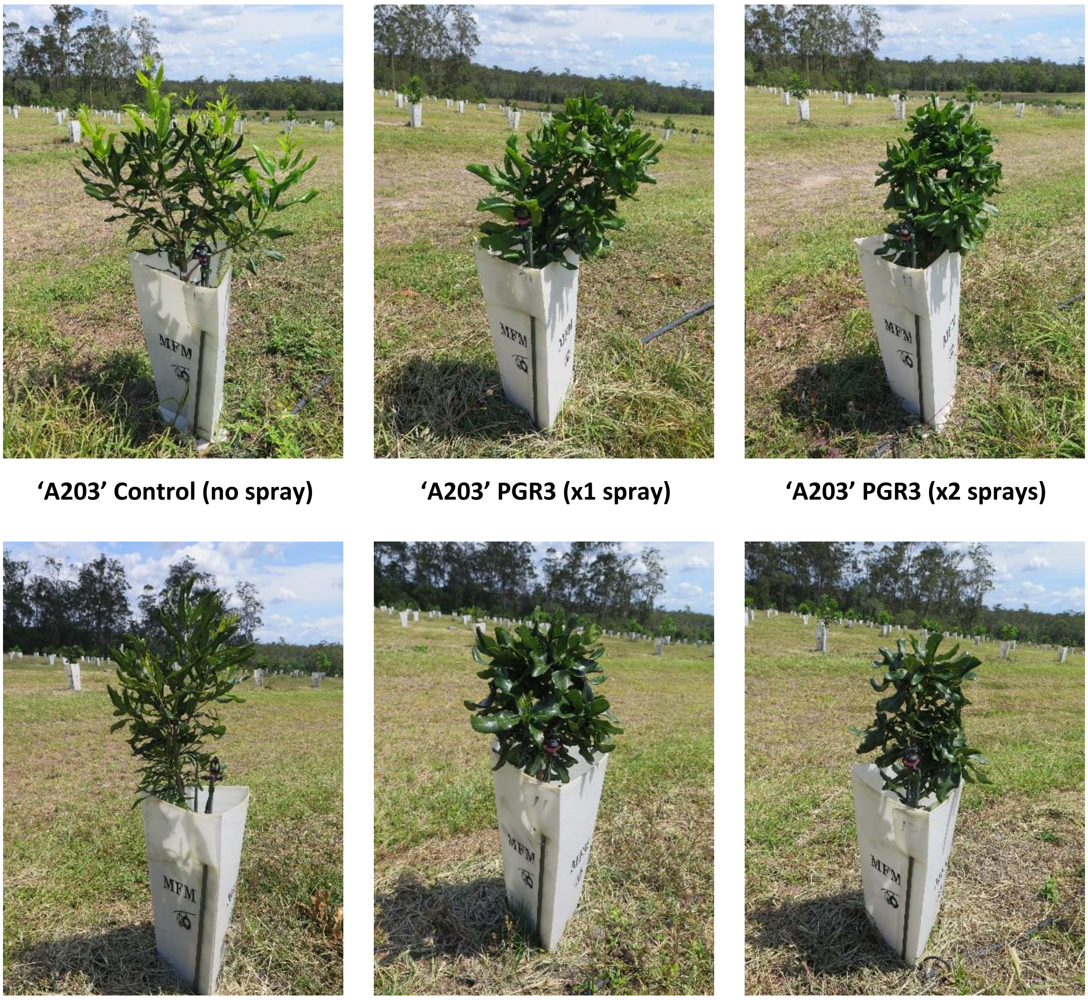


Figure 1. Effect of PGR3 sprays on growth of mini-grafted A203 and 741 macadamia trees. Trees were planted at an orchard near Maryborough in September 2015. PGR treatments were applied on 6 June 2016 at 0.5% (x1 spray) and on 21 December 2015 and 6 June 2016 (x2 sprays) at 1.0 and 0.5% respectively. Images were taken on 11 October 2016.

Table 2. Effect of PGR3 sprays on growth (trunk diameter and tree height) of mini-grafted 'A203' and '741' macadamia trees. Trees were planted in an orchard near Maryborough, Queensland in September 2015 and PGR treatments applied in June 2015December 2015 and/or June and October 2016. Values are mean ± SE (n=14 trees per treatment). Values in each column followed by the same lowercase letters were not significantly different. Significance: NS = Not significant; (*) = *P*<0.10; * = *P*<0.05; ** = *P*<0.01; * = *P*<0.001**

			Trunk diameter[1] (mm)	Tree height (cm)	Trunk diameter[2] (mm)	Tree height (cm)
Cultivar	**Treatment**	**Application date (rate)**	**11 October 2016**		**18 January 2017**	
'A203'	Control		13.4 ± 0.8	122 ± 3.6 a	19.3 ± 0.8 ab	153 ± 3.2 a
	PGR3 #1	21 Dec 2015 (1.0%) + 6 June 2016 (0.5%)	12.0 ± 0.3	103 ± 2.0 b	17.5 ± 0.5 ab	133 ± 3.7 bc
	PGR3 #2	6 June 2016 (0.5%)	11.9 ± 0.6	102 ± 2.9 b	16.9 ± 0.7 b	127 ± 4.5 c
	PGR3 #3	20 Oct 2016 (0.5%)	-	-	19.5 ± 0.6 a	144 ± 3.2 ab
		Significance	NS	***	*	***
'741'	Control		14.2 ± 0.8 a	120 ± 3.8 a	20.4 ± 0.9 a	152 ± 6.6 a
	PGR3 #1	21 Dec 2015 (1.0%) + 6 June 2016 (0.5%)	12.9 ± 0.7 ab	99 ± 3.0 b	17.7 ± 0.9 ab	123 ± 3.6 b
	PGR3 #2	6 June 2015 (0.5%)	12.1 ± 0.3 b	92 ± 2.1 b	16.1 ± 0.8 b	108 ± 5.7 b
	PGR3 #3	20 Oct 2016 (0.5%)	-	-	17.0 ± 0.9 b	123 ± 4.4 b
		Significance	(*)	***	**	***

Table 3. Trunk diameter, tree height and canopy volume of 'A203' and '741' macadamia trees in September 2018. Trees were planted in an orchard near Maryborough, Queensland in September 2015 and treated with PGR3 in June 2015, December 2015 and June 2016, and October 2016. Values are mean ± SE (n=14 trees per treatment). Values in each column followed by the same lowercase letters were not significantly different. Significance: NS = Not significant; (*) = *P*<0.10.

Cultivar	Treatment	Application date (rate)	Trunk diameter (mm)	Tree height (m)	Canopy volume (m^3)
'A203'	Control		58 ± 2.0	3.40 ± 0.14	8.04 ± 0.8
	PGR3 #1	21 Dec 2015 (1.0%) + 6 June 2016 (0.5%)	57 ± 1.4	3.42 ± 0.12	8.00 ± 0.6
	PGR3 #2	6 June 2015 (0.5%)	58 ± 0.9	3.33 ± 0.11	8.19 ± 0.4
	PGR3 #3	20 Oct 2016 (0.5%)	60 ± 1.3	3.41 ± 0.14	9.31 ± 0.6
		Significance	NS	NS	NS
'741'	Control		60 ± 2.0 a	2.79 ± 0.06	2.73 ± 0.3 a
	PGR3 #1	21 Dec 2015 (1.0%) + 6 June 2016 (0.5%)	53 ± 1.7 b	2.63 ± 0.07	1.90 ± 0.2 b
	PGR3 #2	6 June 2015 (0.5%)	58 ± 1.4 ab	2.68 ± 0.06	2.18 ± 0.2 ab
	PGR3 #3	20 Oct 2016 (0.5%)	53 ± 1.8 b	2.58 ± 0.07	1.84 ± 0.2 b
		Significance	(*)	NS	(*)

The first flowering data were recorded from the ‘A203’ trees in September 2017 (the ‘741’ trees did not flower in 2017). The PGR treatments did not appear to affect the number of racemes on the ‘A203’ trees (Table 4). However, not all trees flowered, which contributed to high variability.

Table 4. Effect of PGR3 sprays on flowering in September 2017 of mini-grafted ‘A203’ macadamia trees planted in October 2015 at Maryborough. Values are mean ± SE (n=14 trees per treatment). Significance: NS = Not significant; (*) = *P*<0.10. Data were analysed using transformed data based on square root transformations and back-transformed to the original units for presentation.

Treatment	Application date (rate)	No. of racemes (Sept. 2017)	% of trees flowering	Yield[1] March 2018 (g/tree)
Control		8.3 ± 2.7	79	0.1 ± 0 b
PGR3 #1	21 Dec '15 (1.0%) + 6 Jun '16 (0.5%)	9.5 ± 3.8	57	2.1 ± 0 b
PGR3 #2	6 Jun '16 (0.5%)	6.8 ± 3.9	57	30.9 ± 22 ab
PGR3 #3	20 Oct '16 (0.5%)	12.1 ± 5.4	79	50.6 ± 20 a
	Significance	*NS*		**

[1] Yield = hull + shell + kernel; estimated 55% nut in shell from combined subsample

Project 3. ‘A203’ and ‘A16’, PGR3 applied at full or half rate (1.0% or 0.5%)

A third experiment was set up on slightly older ‘A203’ and ‘A16’ trees (planted in February 2015 compared with October 2015 for Projects 1 and 2) to compare the effect of PGR3 applied at full label rate (1.0%) and at half label rate (0.5%). The treatments were applied on 22 March 2016, after trees had been pruned. The control “unsprayed” trees required a further round of pruning that was completed in June 2016.

By October 2016, with few exceptions, PGR3 treated trees had smaller trunk diameters and were not as tall as control trees (Table 5, Figure 2). These differences were apparent across all cultivars and treatments in September 2017, 17 months after treatment.

Table 5. Effect of PGR3 sprays on trunk diameter and tree height of mini-grafted 'A203' and 'A16' macadamia trees. Trees were planted at an orchard near Maryborough QLD in February 2015 and two PGR treatments (0.5 and 1.0%) were applied on 22 March 2016. Control trees received an additional pruning treatment in June 2016. Values are mean ± SE (n = 7 trees per treatment). Values in each column followed by the same lower-case letters were not significantly different. Significance: NS = not significant; (*) = *P*<0.10; * = *P*<0.05; ** = *P*<0.01.

		Trunk diameter[1] (mm)	Tree height (m)	Trunk diameter[2] (mm)	Tree height (m)
Cultivar	**Treatment**	**11 October 2016**		**18 January 2017**	
'A203'	Control	25.0 ± 1.2	1.59 ± 0.01 ab	33.2 ± 1.3 ab	1.96 ± 0.07 ab
	PGR3 (0.5%)	26.4 ± 1.0	1.61 ± 0.05 a	34.6 ± 1.1 a	2.00 ± 0.08 a
	PGR3 (1.0%)	23.7 ± 0.6	1.47 ± 0.04 b	30.3 ± 0.7 b	1.77 ± 0.07 b
	Significance	NS	(*)	*	(*)
'A16'	Control	25.4 ± 1.5 a	1.51 ± 0.04 a	32.3 ± 1.4 a	1.85 ± 0.06 a
	PGR3 (0.5%)	24.1 ± 0.6 ab	1.49 ± 0.04 a	31.8 ± 0.5 a	1.85 ± 0.04 a
	PGR3 (1.0%)	21.0 ± 1.2 b	1.33 ± 0.04 b	27.5 ± 1.0 b	1.61 ± 0.06 b
	Significance	*	**	**	**

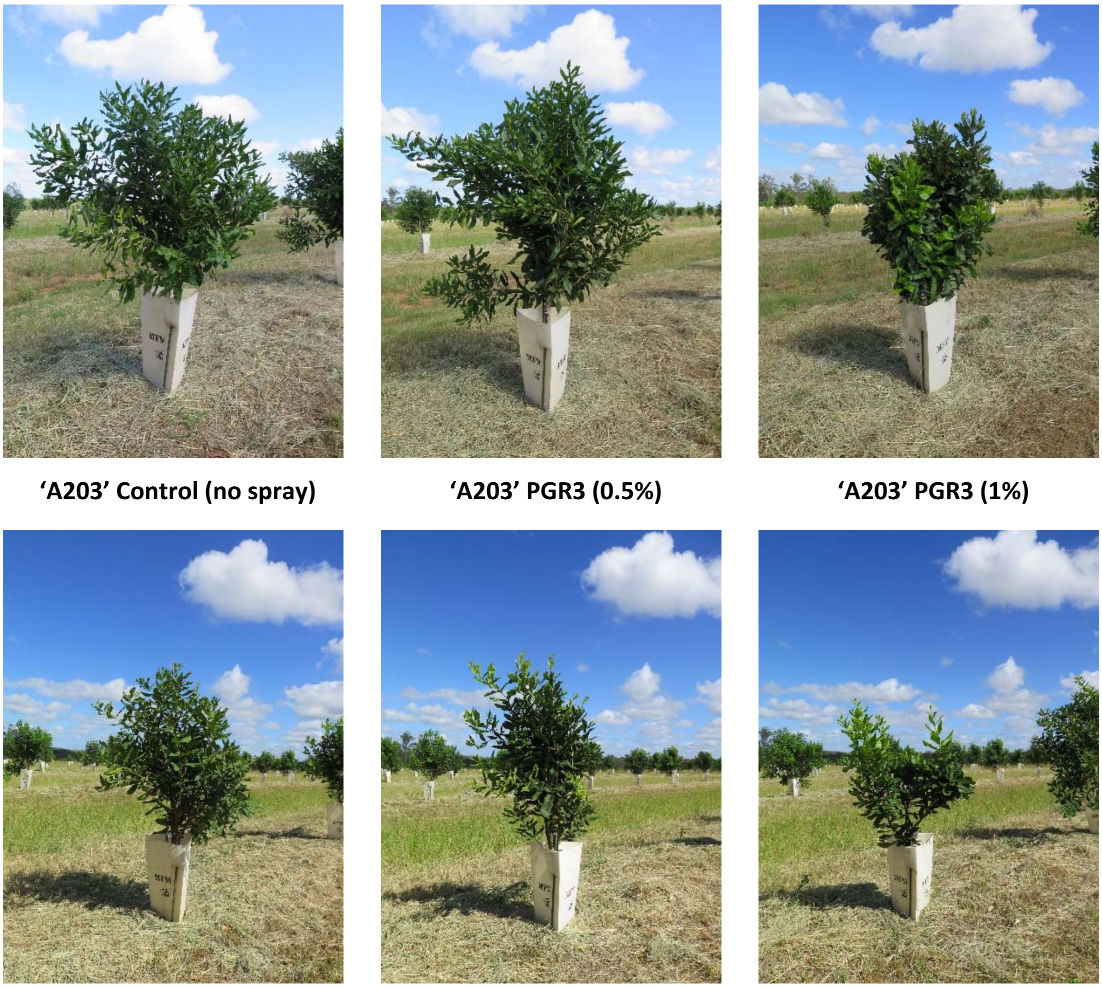
A203 Control (no spray) **A203 PGR3 (0.5%)** **A203 PGR3 (1.0%)**

A16 Control (no spray) **A16 PGR3 (0.5%)** **A16 PGR3 (1.0%)**

Figure 2. Effect of PGR3 sprays on growth of mini-grafted A203 and A26 macadamia trees. Trees were planted in an orchard near Maryborough in February 2015. PGR treatments were applied on 22 March at 0.5% and 1.0%. Images were taken on 11 October 2016.

Our impression was that the 1% PGR3 dose was too high. PGR3 is an anti-gibberellin that inhibits shoot extension producing shorter internodes and thus closer leaf spacing. Although we ended up with a smaller canopy, the trunk diameters were also smaller and the leaf canopies were relatively dense as the leaves have ended up being compressed into a relatively short length of stem (Figure 2).

The 0.5% PGR3 treatment appeared to produce a more desirable result. While our data show little effect of the 0.5% PGR3 treatment on tree size and trunk diameter compared with the control trees, it must be remembered that the control trees had received a second round of pruning to reduce/contain tree size. The PGR3 treated trees did not receive this additional pruning. So the PGR treatment applied 12 months after planting was able to contain tree growth and thus avoid the need for additional summer pruning over the 12 months following treatment (Figure 3).



‘A203’ Control (no spray) **‘A203’ PGR3 (0.5%)** **‘A203’ PGR3 (1%)**

‘A16’ Control (no spray) **‘A16’ PGR3 (0.5%)** **‘A16’ PGR3 (1%)**

Figure 3. Effect of PGR3 sprays on growth of mini-grafted ‘A203’ and ‘A16’ macadamia trees. Trees were planted in an orchard near Maryborough, Queensland in February 2015. PGR treatments were applied on 22 March 2016 at 0.5% and 1%. The control trees received an additional round of pruning in June 2016. Images were taken on 18 January 2017.

All of the ‘A203’ trees flowered in September 2017 (Table 6). Although there were no significant differences between treatments, several of the PGR3 (0.5%) treatment trees produced unusually high numbers of racemes, indicating a highly variable response to treatment (Figure 4). It is possible that a significant response might have been observed if there were more treatment replicates. A “Two-Sample T-test Assuming Unequal Variances” to compare means from the control and the PGR3 (0.5%) treatment trees also showed no significant difference ($P = 0.13$). There was a trend for yield to be higher on the Control and PGR3 (0.5%) treatment trees than the higher rate (1.0%) PGR3 treatment trees. This may have been a consequence of the 1.0% label rate being too strong for these trees and causing significant stunting of shoot growth. What is clear is that macadamias are extremely responsive to this PGR.

Not all of the ‘A16’ trees flowered in 2017 (Table 6). However, it appeared that the PGR3 (1.0%) treatment may have increased the number of racemes compared with the untreated control trees, although this difference was not significant. A smaller and also non-significant response was observed with the PGR3 (0.5%) treatments. Yields were similar from all treatments although the Control trees tended to have the lowest cropping levels, but this was not significant.

Table 6. Effect of PGR3 (Plant Growth Regulator 3) sprays on flowering in September 2017 and cropping in March 2018 of mini-grafted 'A203' and 'A16' macadamia trees planted in February 2015 in Maryborough, Queensland. Two PGR treatments (0.5 and 1%) were applied on 22 March 2016. Control trees received an additional pruning treatment in June 2016. Values are mean ± Standard Error (n = 7 trees per treatment). Values followed by the same lowercase letters were not significantly different. Data were analysed using transformed data based on square root transformations and back-transformed to the original units for presentation. Significance: NS = Not Significant; (*) = *P*<0.10.

Cultivar	Treatment	No. of racemes (per tree)	Total crop[1] (kg per tree)	% of trees with crop
		Sept. 2017	**March 2018**	
'A203'	Control	72 ± 11	2.44 ± 0.6 ab	100
	PGR3 (0.5%)	158 ± 55	3.53 ± 1.1 a	100
	PGR3 (1.0%)	52 ± 23	0.79 ± 0.3 b	100
	Significance[1]	*NS*	*(*)*	
'A16'	Control	3 ± 1 b	0.36 ± 0.1	71
	PGR3 (0.5%)	14 ± 8 ab	0.71 ± 0.3	86
	PGR3 (1.0%)	38 ± 11 a	1.25 ± 0.4	86
	Significance	*(*)*	*NS*	

[1] Total crop = hull + shell + kernel; estimated 55 and 53% nut in shell from combined subsample for 'A203' and 'A16', respectively.

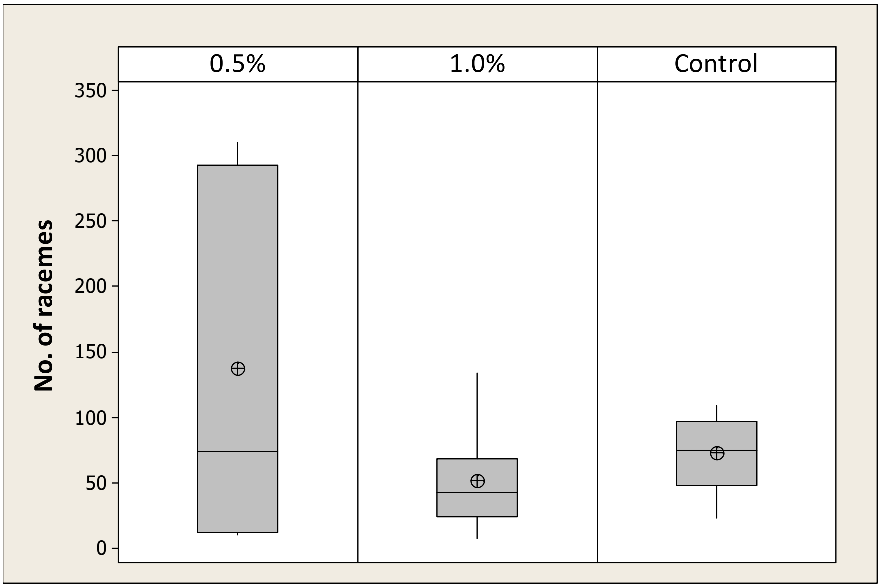


Figure 4. Box plot showing the number of floral racemes on mini-grafted 'A203' macadamia trees in September 2017. Trees were planted in February 2015 in Maryborough and sprayed with PGR3 treatments (0.5 and 1%) on 22 March 2016. Control trees received an additional pruning treatment in June 2016. The bottom and top of the boxes represent the 25th and 75th percentiles, respectively. The median value is visible as a horizontal line and the mean value is visible as a symbol within each block.

Overall with the trials at Maryborough there is a suggestion that treatments which created a smaller, denser canopy increased the propensity of these trees to produce flowers. This is counter-intuitive as one would expect fewer flowers with less light inside a dense canopy. However, it does fit with the overall bearing pattern of macadamia trees, in which flowers are consistently produced on the inside of the tree canopies in regions with low incident light.

PGR3 is an anti-gibberellin that inhibits shoot extension giving shorter internodes and thus closer leaf spacing. With higher concentrations, leaves end up being compressed into a relatively short length of stem which could create issues with spray coverage and harbouring of insect pests. It will therefore be important to evaluate a further range of concentrations and timings on trees of different ages before final recommendations can be made.

APPENDIX VIII Use of trunk girdling to promote earlier flowering and cropping on three- and four-year-old macadamia trees

Introduction:

Increasing yields from young trees and thus reducing the time to first commercial harvest is a key target for growers establishing new macadamia farms. Commercial harvest means that there is sufficient crop on the trees to warrant the use of harvesting machines to collect the crop. If there is insufficient crop to warrant machine harvesting, growers will either hand harvest the crop, which is expensive, or they will leave the crop in the orchard.

Trunk girdling is one technique used in several tree and vine crops to increase flowering and cropping on young plants that could have application with macadamia to reduce the time to the first commercial harvest. Timing of girdling is critical to obtaining the desired response. Trunk girdles applied in late winter before flowering can increase fruit set; applied after flowering can increase fruit size; applied in mid-summer can increase carbohydrate accumulation and taste of fruit, while applied later in summer at the time of floral initiation trunk girdling can increase the number of flowers in the subsequent spring. This project evaluated the use of trunk girdling macadamia trees in late summer to increase flowering on trees about to set their first commercial crop.

Materials and methods:

Two trunk girdling projects were established at a trial site in Knockrow NSW, to evaluate the use of trunk girdling to promote earlier flowering and cropping on existing three- and four-year-old '344' trees grafted using the traditional method onto H2 seedling rootstocks and planted in June 2013 and February 2012, respectively. Treatments (plus a non-girdled control) included application of a 2.0 mm and 5.0 mm wide trunk girdle, were applied on 29 March 2016 (Figure 1).

Once harvest had been completed in March 2017, new 5 mm girdles were applied to the 3-year-old trees that had received a 5 mm cut in the previous year to gauge the benefit of repeat girdling over 2 years in terms of time taken to the first commercial harvest. The 3-year-old trees with the 2 mm cut in the previous year and the 4-year-old trees were not repeat girdled in 2017 so that we could determine the consequences of doubling yield in one year on the cropping ability of trees in the next year.

The four-year-old trees had a small crop (< 10 nuts/tree) at the time of girdling in 2016 and were expected to produce their first significant crop in 2017. The three-year-old trees had not produced any crop at the time of treatment; they were expected to produce some flowers in spring 2016 but their first significant crop was not expected until the 2018 season.

Trunk diameter recorded above and below the girdle and tree dimensions (height and canopy volume) were recorded in 2016, 2017 and 2018. Canopy volume was determined from digital images taken at right angles to each tree along the row. ImageJ Fiji software (http://imagej.nih.gov/ij) was then used to trace the perimeter of the tree canopy from which to calculate cross-sectional canopy area. This cross-sectional area was then converted to a circle from which it was possible to calculate radius. Canopy volume (V) was calculated as $V = 4/3*\pi*radius^3$. All trees were isolated and not growing into each other so it was valid to assume a uniform canopy cross-section regardless of the angle at which the digital image was taken.

The number of racemes were counted in spring 2016, the first year of flowering, and in 2017. Trees were hand harvested in March 2017 and 2018. Fruit were weighed to give total fresh weight per tree, then hulled on-site and weighed again to give total nut in shell (NIS) per tree. Three subsamples (approximately 600 g each) from three or four trees per treatment (n = 3 subsamples) were taken to a commercial facility to determine moisture content. Data on total yield of nut in shell per tree were then adjusted to 10% moisture content.

Treatments were applied in a systematic design with 10 trees per treatment alternating along the row with one age class of tree per row. Statistical analyses were done using Minitab v18 statistical software with mean separation by Tukey-Kramer method, $P \leq 0.05$.

Figure 1. Effect of trunk girdling treatments on flowering on 4-year-old '344' macadamia trees at Knockrow, NSW (bottom photos). Girdles were applied in March 2016 and had fully healed over by June 2016 (top photos).

Results and discussion:

Trunk girdling treatments had caused a slight swelling of the trunks above the girdle by October 2016, six months after treatment (Table 1, Figure 1). This result is consistent with previous girdling studies on other crops and an indication that the girdles had blocked the flow of assimilates from the leaf canopy to the roots. At this stage, the girdles had not affected tree height, but they had a dramatic effect on flowering.

Trunk girdling increased the number of floral racemes in spring 2016 by three-fold on both the 3- and 4-year-old trees. Subsequent yield data collected in summer 2017 showed a doubling of harvested crop on the 3-year-old trees compared with the controls (Table 2). A similar result was recorded in response to a 5 mm wide girdle applied to 4-year-old trees, with a lesser although non-significant effect (*P*=0.096) for the 2 mm girdle. None of the girdling treatments appeared to affect average kernel size or moisture content at harvest (data not presented).

Table 1. Effect of trunk girdling treatments on tree growth and flowering on 3- and 4-year-old '344' macadamia trees at Knockrow, NSW. Treatments were applied using a 2.0 mm or 5.0 mm VACA girdling tool on 29 March 2016. Data were collected in October 2016. Values are mean ± SE (n = 10 trees per treatment).

Cultivar	Treatment	Trunk diameter (mm)			Tree height (m)
		Below girdle	**Above girdle**	*Significance*[1]	
3-year-old	Control – no girdle	54 ± 2.6	X		2.40 ± 0.8
	2.0 mm girdle	53 ± 0.9	58 ± 1.6	**	2.37 ± 0.2
	5.0 mm girdle	52 ± 1.9	55 ± 1.6	**	2.39 ± 0.4
	Significance	*NS*	*NS*		*NS*
4-year-old	Control – no girdle	76 ± 2.4	X		3.05 ± 0.4
	2.0 mm girdle	75 ± 1.9	80 ± 1.8	***	2.92 ± 0.6
	5.0 mm girdle	76 ± 2.4	80 ± 1.5	*	3.03 ± 0.5
	Significance	*NS*	*NS*		*NS*

[1] Determined using Paired T-Test to compare trunk diameter below and above the girdle.

Table 2. The effect of trunk girdling treatments applied in March 2016 to 3- and 4-year-old '344' macadamia trees growing at Knockrow, New South Wales, on the number of floral racemes in October 2016, number of nuts per tree and yield of nut in shell (NIS) per tree and per hectare in March 2017 (1 year after treatment application). Values in each column for the same age class, followed by the same lower-case letters were not significantly different. Significance: NS = Not Significant; * = *P*<0.05; ** = *P*<0.01; * = *P*<0.001**

Tree age[1] (at time of girdling)	Treatment	Racemes per tree (October 2016)	Nuts per tree (March 2017)	Yield (March 2017) kg/tree NIS[2]	t/ha NIS
3-year-old	Control - no girdle	22 ± 6 b	43 ± 16 b	0.37 ± 0.13 b	0.09 ± 0.03 b
	2.0 mm girdle	59 ± 10 a	108 ± 17 a	0.83 ± 0.13 a	0.20 ± 0.03 a
	5.0 mm girdle	52 ± 5 a	105 ± 11 a	0.82 ± 0.09 a	0.20 ± 0.02 a
	Significance	**	**	*	*
4-year-old	Control - no girdle	140 ± 24 b	195 ± 45 b	1.62 ± 0.4 b	0.40 ± 0.09 b
	2.0 mm girdle	325 ± 36 a	285 ± 33 ab	2.40 ± 0.3 ab	0.59 ± 0.07 ab
	5.0 mm girdle	362 ± 41 a	391 ± 39 a	3.20 ± 0.3 a	0.79 ± 0.07 a
	Significance	***	**	**	**

[1] Tree age at time of first girdling treatment in March 2016

[2] Yield data are adjusted to 10% moisture content

In September 2017, there were similar numbers of racemes on all girdled and non-girdled trees from the 2016 treatments and likewise in May 2018 there were no significant differences in yield (Table 3). Hence there was no evidence that the higher yields on these trees from the 2016 girdling treatments had a negative effect on return bloom in spring 2017 and cropping in 2018. However, unexpectedly, the repeat girdling treatment applied in March 2017 did not increase the number of racemes in spring (September 2017) or fruit yield in autumn (May 2018). It is possible that this lack of positive response to the repeat girdling treatment was related to the unusually low winter rainfall in this district in 2017. In the previous 3 years, rainfall during July and August ranged from 134 to 418 mm, while in 2017 there was just 18 mm (Table 4).

Table 3. The effect of trunk girdling treatments applied to 3- and 4-year-old '344' macadamia trees in March 2016 on the number of floral racemes in October 2017 and yield of nut in shell (NIS) per tree and per hectare in March 2018 (2 years after first treatment application). The 5 mm girdling treatment on 3-year-old trees was repeated in March 2017. Significance: NS = Not Significant

Tree age[1] (at time of girdling)	Treatment	Racemes per tree (October 2017)	Yield (May 2018) kg/tree NIS[2]	Yield (May 2018) t/ha NIS
3-year-old	Control - no girdle	277 ± 20	3.17 ± 0.3	0.78 ± 0.07
	2.0 mm girdle	313 ± 32	3.33 ± 0.2	0.82 ± 0.06
	5.0 mm girdle	322 ± 29	3.02 ± 0.2	0.75 ± 0.06
	Significance	*NS*	*NS*	*NS*
	P =	*0.518*	*0.716*	*0.716*
4-year-old	Control - no girdle	nd[3]	6.21 ± 0.4	1.56 ± 0.11
	2.0 mm girdle	nd	6.02 ± 0.6	1.52 ± 0.15
	5.0 mm girdle	nd	6.18 ± 0.3	1.56 ± 0.07
	Significance		*NS*	*NS*
	P =		*0.951*	*0.951*

[1] Tree age at time of first girdling treatment in March 2016
[2] Yield data are adjusted to 10% moisture content
[3] nd = no data

Table 4. Rainfall at Knockrow, New South Wales, during July and August in the years 2014 to 2017 recorded at the Ballina Airport (10 km south of the trial site).

Year	Winter (July and August)
2014	418 mm
2015	134 mm
2016	175 mm
2017	18 mm

[1] Data sourced from Australian Bureau of Meteorology (http://www.bom.gov.au/)

All girdled trees, including those receiving just the single girdle treatment in 2016, tended to be smaller and appeared to have delayed vegetative growth compared with the control trees so there was some indication of stress in response to girdling and possibly the low rainfall season (Table 5). Although not always significant ($P<0.05$) there was a consistent trend in June and September 2017 and in May 2018 for girdled trees to be smaller than non-girdled control trees and for the trees with the more severe trunk girdle (5.0 mm wide girdle) to be smaller than the 2.0 mm girdle trees. So although yields in response to girdling were either higher or similar to yields on non-girdled control trees, these yields on the girdled trees were obtained from slightly smaller trees which may have a benefit in the longer term, even from these one-time-only girdling treatments.

Table 5. The effect on canopy volume of trunk girdling treatments applied to 3- and 4-year-old '344' macadamia trees in March 2016 at Knockrow, New South Wales. Treatments were applied using a 2 mm or 5 mm VACA girdling tool. The 5.0 mm girdling treatment trees were repeat girdled in March 2017. Values are mean ± Standard Error (n=10 trees per treatment). Values followed by the same lowercase letters were not significantly different. Significance: NS = Not Significant; ** = *P*<0.01.

Tree age[1] (at time of girdling)	**Treatment**	**Canopy volume (m^3)**		
		June '17	**Sept '17**	**May '18**
3-year-old	Control - no girdle	1.9 ± 0.2	3.4 ± 0.3 a	6.7 ± 0.5 a
	2.0 mm girdle (2016)	1.7 ± 0.2	2.7 ± 0.2 ab	5.2 ± 0.3 b
	5.0 mm girdle (2016 and 2017)	1.6 ± 0.1	2.3 ± 0.2 b	4.8 ± 0.3 b
	Significance	*NS*	**	**
4-year-old	Control - no girdle	5.3 ± 0.4	6.6 ± 0.5	10.0 ± 1.1
	2.0 mm girdle (2016)	4.7 ± 0.2	5.6 ± 0.3	9.6 ± 0.5
	5.0 mm girdle (2016)	4.6 ± 0.4	5.9 ± 0.4	8.8 ± 1.2
	Significance	*NS*	*NS*	*NS*

[1] Tree age at time of first girdling treatment in March 2016

The significance of this result for 4-year-old trees is that by doubling the crop to over 2 kg/tree NIS we have advanced the first commercial harvest for these trees by 1 year, with potential to harvest by machine. While growers will generally harvest the lighter crops on young trees by hand, once the crop reaches a critical volume then machine harvesters are used, which is considerably more cost effective than hand harvesting. This is an important result for industry that warrants further investigation across different sites and with different cultivars.

APPENDIX IX Project activities

Project field work:

21 October 2014.	Treatments applied for PGR trials at Gray Plantation's nursery, Eureka NSW
18 November 2014.	Data collection from PGR trials at Gray Plantation's nursery, Eureka NSW
22 December 2014.	Data collection from PGR trials at Gray Plantation's nursery, Eureka NSW
9 February 2014.	Data collection from PGR trials at Gray Plantation's nursery, Eureka NSW
18 August 2015.	Marked out trial sites at Maryborough QLD
6 October 2015.	Collected cutting grown trees for research projects from Hideaway Nursery, Beerwah QLD
7-8 October 2015.	Planting trees in trial site at Maryborough QLD
12 October 2015.	Data collection and application of management treatments for trees at Maryborough QLD
17-18 November.	Data collection from trees at Maryborough QLD
9-11 December 2015.	PGR treatment application and data collection from trees at Maryborough QLD
21 December 2015.	PGR treatment applications to trees at Maryborough QLD
2 February 2016.	Data collection from trials at Maryborough QLD
15 March 2016.	Planting new trees and data collection for trials at Maryborough QLD
22 March 2016.	PGR treatment applications for trials at Maryborough QLD
29 March 2016.	Established girdling trials at Knockrow NSW
6 June 2016.	Data collection and tree management at trial site in Maryborough QLD
22 June 2016.	Data collection from girdling trial at Knockrow NSW
10 October 2016.	Collected flowering data from girdling trial at Knockrow NSW
11 October 2016.	Data collection from trials at Maryborough QLD
20 October 2016.	PGR treatment applications at Maryborough QLD
18 January 2017.	Data collection from trials at Maryborough QLD
20-22 March 2017.	Harvested fruit from girdling trials at Knockrow NSW
9 June 2017.	Data collection from girdled trees at Knockrow NSW
4 September 2017.	Flower counts on girdled trees at Knockrow NSW
5 September 2017.	Data collection from trials at Maryborough QLD
18-19 December 2017.	Data collection from trials at Maryborough QLD
15 March 2018.	Harvested research trials at Maryborough QLD
6-8 May 2018.	Harvested research trials at Knockrow NSW
18-19 September 2018.	Flower counts on girdled trees at Knockrow NSW

Industry meetings:

15 August 2015.	Small trees meeting, invited presentation on "small trees" research UQ Brisbane QLD
19 August 2015.	Met with David Bell to discuss supply of cutting grown trees for Maryborough trial site, Beerwah QLD
27 August 2015.	Met with Ross Burgess, Macadamia Direct to discuss macadamia research and potential trial sites, Knockrow NSW
27 August 2015.	Met with Rob Colefax to discuss macadamia research, Alstonville NSW
28 August 2015.	Stahmann Farms Pecan "propagation and precocity" meeting, Moree NSW
11 October 2015.	Meeting with Scott Alcott (Macadamia Farm Management) and Adrian Forrest re supply of mini-grafted trees for research trials, Bundaberg QLD
14 October 2015.	Meeting with Kim Wilson, Ray Norris and Chris Searle (Macadamia nurserymen and consultants) to discuss project, Lismore
15 – 17 October 2015.	Macadamia Industry Conference, Lismore. Invited Small trees presentation.
10 December 2015.	Met with Robbie Commens (AMS) and Andrew Pierce (Consultant) to view research trials at Maryborough QLD
2 February 2016.	Met with Scott Alcott, David Nel and David Harris to discuss macadamia research trials at Maryborough QLD
22 March 2016.	Met with Robbie Commens (AMS) to review girdling trial data at Knockrow NSW
28-29 March 2016.	Attended Australian Nut Congress, Sydney
6 June 2016.	Met with John Wilkie (DAFQ) to review research program at Maryborough QLD
7-8 June 2016.	Attended AMS Macadamia Consultants Workshop, Virginia QLD
9 July 2016.	Met with NSW Dept of Agriculture staff at Alstonville NSW to discuss potential collaboration on macadamia research
10 July 2016.	Met with Jolyon Burnett (CEO) and Robbie Comments from the Australian Macadamia Society in Lismore NSW to review macadamia research and identify potential grower collaborators for future field trials
11 August 2016.	Met with Scott Allcott from Macadamia Farm Management in Bundaberg QLD to establish new collaborative trials on their macadamia plantation at Maryborough
19 August 2016.	Met with David Bell from Hidden Valley Nursery in Beerwah QLD to establish collaborative trials to evaluate clonal macadamia trees
27 August 2016.	Met with Ross Burgess from Macadamia Direct in Lismore NSW to discuss new collaborations on macadamia research
6 June 2016.	Met with John Wilkie from DAFF Queensland in Maryborough QLD to review our macadamia research projects and opportunities for future collaborations
8 June 2016.	Attended Australia Macadamia Society Consultants workshop in Brisbane QLD to present summary of our macadamia productivity research
19 October 2016.	Attended AMS Conference in Caloundra QLD
28-29 Mar 2017.	Represented PFR at Australian Nut Industry Congress, in Melbourne
6-7 June 2017.	Attended Australian Macadamia (AMS) Society Macadamia Consultants Workshop to present data on young tree productivity trials
1-2 August 2017	Attended Hort Innovation Macadamia Physiology Workshop in Bundaberg QLD to provide invited presentation on macadamia tree physiology and priorities for future research
13-14 September 2017.	Attended Macadamia Symposium in Hilo Hawaii
13-15 November 2018.	Attended AMS Conference in Gold Coast QLD.