ESTABLISHMENT OF HIGH-DENSITY MANGO ORCHARDS

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Peer Review Statement

The CRCNA recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.

The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2018),

and provided constructive feedback which was considered and addressed by the author(s).

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Acronyms

DAF Department of Agriculture and Fisheries

KP Kensington Pride mango variety

PGR Plant Growth Regulator such as Paclobutrazol

Project Participants

Executive Summary

This manual contains seven factsheets created to support growers who are considering intensifying or have already begun moving towards higher density mango orchards. Information on both 'slim-hedge' and trellised high-density systems is provided in this manual.

Factsheet 1: 'Making the change to high density mango orchards' This factsheet details the factors that have influenced the move by the Australian mango industry towards higher planting densities including some of the barriers that have slowed this movement. The development of lower-vigour mango varieties over recent decades has helped reduce these barriers and most new plantings are being planted at progressively higher densities. There is still great potential for further intensification within the mango industry. Intensification affords numerous advantages such as higher yields per hectare, lower chemical and resource inputs per kilogram of fruit, more efficient harvesting, and improved suitability to automation. These advantages exceed the additional upfront costs and upskilling required for managing higher density orchards.

Factsheet 2: 'Economics of high density mango orchards' This factsheet summarises the key findings from the report '*Economics case study of intensive mango systems: A comparison of the profitability of conventional (low, medium & high density) and trellis (high density) mango canopy systems in north Queensland based on early trial results*' (Bennett and Dickinson, 2021) available on the Cooperative Research for Northern Australia's (CRCNA) website at https://crcna.com.au/resources/publications/economic-case-study-intensive-mango-systems. The gross margin analysis (based on 6-year trial results from the DAF Walkamin Research Facility) found that while higher density orchards were initially more costly to set up than conventional low-density orchards, their earlier and higher yields easily compensated for the additional initial investment. The report also found that variable input costs (such as pest, disease and weed control, irrigation and nutrition) were lower per kilogram of fruit produced for higher density orchards when compared to low density orchards e.g. $1.70/kg for high density (1,242 trees/ha) versus $2.11/kg for low density (207 trees/ha).

Factsheet 3: 'Choosing mango tree spacing' This factsheet presents a brief summary of mango orchard planting densities from the early years (1960s-1980s) through to the present and the predicted planting densities of orchards of the future. The factsheet covers the four factors growers should consider when determining tree spacing: 1) The mango variety; 2) The minimum inter-row width required for machinery access at harvest; 3) The maximum desired tree height at harvest; and 4) The maximum desired tree width at harvest.

Factsheet 4: 'Trellis versus hedge designs' When considering high density plantings, two main systems emerge as options for mango orchards: trellised or slim-hedge designs. The aim of both systems is to create a narrow canopy that maximises surface area and minimises volume. Trees with large canopy volumes have large internal voids that harbour pests and diseases and are more difficult to harvest than narrower trees. This factsheet outlines the advantages and disadvantages of each system to support growers' when choosing which system is best suited to their situation.

Factsheet 5: 'Trellis design and construction' This factsheet is aimed at growers considering implementing a trellis system and builds on recommendations from the AgriFutures report '*Improving the Capacity of Primary Industries to Withstand Cyclonic Winds*' available at https://www.agrifutures.com.au/product/improving-the-capacity-of-primary-industries-to-withstand-cyclonic-winds/. Details of the materials required such as posts, wires and end assemblies, and the installation methods are outlined in this factsheet. The costs per hectare are also summarised to provide an indication of the upfront capital investment required to implement a trellised system.

Factsheet 6: 'Trellis pruning and training' Mango trees grown on trellises require specialised pruning and training to ensure trees fill out the trellis quickly and effectively and maximise the number of fruiting terminals. There are a number of trellis training systems, that have been trialled in mangoes including espalier, palmette and tatura methods. The espalier training method – where tree limbs are trained horizontally along the trellis wires – is covered in detail in this factsheet. Topics covered include the equipment required, first prune and the first limb training through to how to manage mature trees.

Factsheet 7: 'High density hedge (slim-hedge) design, pruning and training' Mango hedge systems are not a new concept and older wide-spaced trees have often been allowed to grow into hedges. What sets high-density slim hedges apart is their very narrow canopy widths of no more than 3 metres wide. The final factsheet details the principles, characteristics and considerations of a slim-hedge orchard and outlines the benefits of these orchard designs such as improved harvesting efficiency and more efficient use of site and light resources. For growers with low density, conventional orchards considering retrofitting high density orchard to existing blocks, the factsheet suggests a staged approach where older trees are removed and blocks replanted at a higher density.

Factsheet 1: Making the change to high density mango orchards

Why intensify?

Maintaining profitability in an environment of ever-increasing costs is a major challenge facing Australian mango growers. A key priority for the Australian mango industry is to increase industry productivity per hectare through increased yields and reduced costs (Hort Innovation, 2017). To achieve these goals, improved productivity is essential, however, this is challenging with conventional planting densities often less than 200 trees per hectare. Yields per hectare vary annually, but on average, Kensington Pride (KP, the main industry variety) yields 35 – 70kg per tree or 7 – 13 tonnes per hectare at a spacing of 185 trees/ha (DPI, 1999). Opportunities exist to improve productivity through intensification.

An intensification program within the apple and pear industry (Future Orchards®) initiated in 2006, has substantially increased industry average production from 10-20 up to 35-55 tonnes/ha, with some orchards achieving over 100 tonnes/ha (Crawford, 2016; APAL, 2019). This success has been achieved through the adoption of new canopy systems including trellis and non-trellis designs, which incorporate smaller trees, grown at higher densities, with narrow, more open canopies. These systems increase canopy surface area per hectare and improve light interception and light distribution, which in turn results in improved productivity.

Figure 1. Apples grown on trellis systems. The success of high-density orchards in the apple and pear industries (Future Orchards®) has inspired high density trials in other tree crops, including mango.

Challenges for mangoes

High density systems also have great potential for mango orchards, however, one of the main challenges posed by intensifying mango trees is vigour control (Bally and Ibell, 2015; Menzel & Le Lagadec, 2017). Most mango varieties grown in Australia are vigorous (particularly Kensington Pride) and if left unmanaged can easily grow to heights greater than 10m. The use of trellising and/or intensive branch training and pruning methods has been successfully used as a tool by the apple and pear industry to manage vigour (Crawford, 2016). These methods may also enable mango orchards to be grown at higher densities and significantly improve productivity. Other expected advantages of smaller trees grown at higher densities include; more efficient harvesting, better adaptation to mechanisation and robotics, greater efficiency of pest and disease management (Bally and Ibell, 2015; Bally et al., 2020; Menzel & Le Lagadec, 2017) and greater cyclone resilience (Drinnan *et al.* 2018).

Figure 2. The Kensington Pride mango variety is extremely vigorous, making it less suitable for high density orchards.

Industry Adoption

The Australian mango industry has experienced a gradual shift towards increased planting density over the past 20 years, as new varieties with less vigour than KP have been planted. These include R2E2, Keitt, Honey Gold™ and Calypso®. There are a number of well managed R2E2 and Keitt orchards with up to 555 trees/ha. Semi-dwarf varieties such as Calypso®, have been commercially planted at densities up to 357 trees/ha.

Figure 3. An example of an R2E2 mango orchard in Bowen, Queensland, planted over 20 years ago at high density (6x3m or 555 trees/ha).

Research trials

A study by Drinnan *et al*. (2018) found that mangoes grown at Mareeba under a high-density trellis system (5x3m) also showed good applicability to this system. In response to these national orchard system trends, the Queensland Department of Agriculture and Fisheries (DAF) commenced the Small Tree High Productivity Initiative in 2012. This initiative aims to help transform tropical and sub-tropical fruits from low-yielding, low density orchards into high yielding, high density orchard systems. Under this initiative and with funding support from Hort Innovation using the cross-industry R&D levy, a large, replicated, planting systems trial (PST) was established at the DAF Walkamin Research Facility in 2013, incorporating three mango varieties grown at a range of planting densities using conventional and trellis methods. Early results from this trial have been very promising and suggest mangoes have high potential for improved productivity when grown in higher density systems (Bally *et al*., 2020).

Figure 4. A mango planting systems trial that includes trellised and non-trellised planting densities of 1250 trees/ha has been running at Walkamin Research Facility since 2013. The new hybrid variety NMBP-1243 (pictured) is one of three varieties being trialled, along with Calypso® and Keitt.

Table 1 Advantages and disadvantages of high-density mango orchards

Advantages	Disadvantages
Higher yields/ha	Higher establishment costs per hectare
Greater input efficiency per kg of fruit produced	Higher early management costs per hectare
Higher profitability	More management complexity
Smaller trees are easier to harvest	Cannot use large machinery
Suited to robotic harvest technology	More pruning required
More efficient pesticide use per hectare	Requires staff training
Less prone to cyclone damage	Difficult to manage tree vigour
	Risks of greater fruit sunburn

Economic implications

Adopting a new orchard management system poses numerous risks, but of chief concern among growers are the economic implications of this decision. High density systems – particularly trellis systems – require significant upfront investment in infrastructure and additional labour for pruning and training. In new systems, these costs are challenging for growers to accurately estimate, and subsequently make informed decisions about moving to higher density designs.

Fact sheet 2: Economics of high-density mango orchards

Results from the Small Trees High Productivity Initiative at the Queensland Department of Agriculture and Fisheries (DAF) Walkamin Research Facility near Mareeba, are demonstrating that mangoes can be grown with high productivity at high densities, using both traditional hedging and trellising methods. Varieties studied include Calypso®, NMBP-1243 and Keitt. Seven years of yield and management system input data have now been collected. (Calypso® yield data is presented in Figure 5). Trial results are showing that the extra costs of establishing trees at higher densities can be quickly recouped via greatly increased early yields per hectare, resulting in increased orchard profitability from an early age.

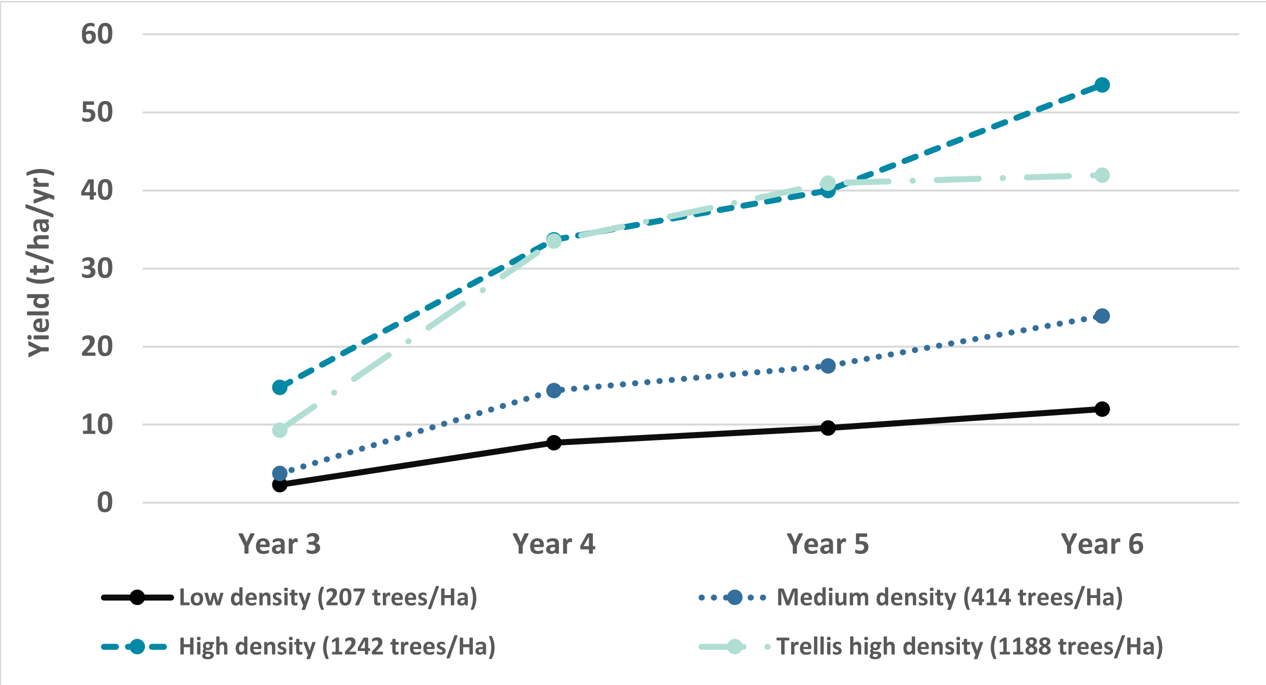

Figure 2. Calypso® yields (t/ha) to age 6 years, for 4 mango density systems at the DAF Walkamin Research Facility.

A gross margin analysis of a range of intensive mango systems was undertaken that compared conventional mango planting systems at three different densities – low (207 trees/ha), medium (408 trees/ha) and high (1242 trees/ha) and one trellised planting system at high density (1188 trees/ha). The mango variety B74 (Calypso®) was selected as the focus variety for the study. This analysis used data from the DAF Planting System Trial (PST), the Australian mango industry, growers, industry stakeholders and published reports.

The following were the per hectare costs and returns expected for each of the planting systems: Low, medium, high density conventional and high-density trellis. The gross margin is the difference between the costs and returns at full production. The costs and returns used in this calculation are outlined in Table 2. The gross margin does not consider fixed costs or capital expenditure. Growers considering transitioning all or part of their farm to a higher density planting system or developing a new farm at increased density should consider undertaking a complete economic analysis specific to their situation. Table 3 outlines the establishment costs required for setting up each of the four systems. Included in the capital outlay costs were land preparation including boom spraying, slashing, ripping and levelling the block in preparation for planting; Irrigation including materials, labour and installation of mainline, sprinklers, taps, connectors and pump and associated infrastructure; Planting expenses included the cost of trees, pre-plant lime and application and tree planting labour; and for the trellis system, the trellis infrastructure.

Table 2 Annual yields and gross margin ($/ha) calculated at full production

Item	Assumptions	Conventional low density 207 trees/ha	Conventional medium density 408 trees/ha	Conventional high density 1,242 trees/ha	Trellis high density 1,188 trees/ha
Yield					
Total yield (tonnes/ha)	Total tree yield	18.2	32.6	58.8	65.9
Harvested yield - HY (tonnes/ha)	5% fruit left in paddock	17.3	31.0	55.9	62.6
Income ($/ha)					
Premium	$4.00/kg @ 77% of HY	53,300	95,505	171,893	192,958
Class 1	$2.00/kg @ 14% of HY	4,845	8,682	15,627	17,541
Class 2	$1.57/kg @ 4% of HY	1,087	1,947	3,505	3,934
Juice/processing	$0.50/kg @ 4% of HY	346	620	1,116	1,253
Reject	$0.00/kg @ 1% of HY	0	0	0	0
Total income ($/ha)		**59,578**	**106,754**	**192,141**	**215,686**
Variable costs ($/ha)					
Nutrition		1,410	2,106	3,132	3,016
Pest management		3,984	5,415	3,478	2,913
Disease management		4,560	6,366	3,179	2,706
Weed management		526	754	876	876
Irrigation		634	1,161	1,576	1,404
Canopy management		1,990	3,587	7,706	6,346
Harvesting		2,933	4,694	8,449	9,485
Packing		11,726	20,806	37,245	41,782
Freight to market		4,391	7,867	14,160	15,895
Commissions & Levies		6,283	11,259	20,264	22,747
Total variable costs ($/ha)		**38,437**	**64,015**	**100,065**	**107,170**
GROSS MARGIN (Total income – Total variable costs)		**21,138**	**42,738**	**92,071**	**108,514**

Table 3 Establishment costs per hectare for the four planting systems

Planting system	Land Prep.	Irrigation	Planting	Trellising	Total
Conventional low density	$1,100	$5,800	$3,591	-	$10,491
Conventional medium density	$1,262	$7,513	$7,078	-	$15,853
Conventional high density	$1,262	$12,676	$21,549	-	$35,487
Trellis high density	$1,262	$12,792	$20,612	$31,981	$66,647

The full CRCNA report ‘Economic Case Study of Intensive Mango Systems: A comparison of the profitability of conventional (low, medium & high-density) and trellis (high-density) mango canopy systems in north Queensland based on early trial results’, is available at: https://crcna.com.au/resources/publications/economic-case-study-intensive-mango-systems.

Fact sheet 3: Choosing mango tree spacing

In the early years of the Australian mango industry (1960s – 1980s) mango trees were regularly planted at low density spacings of 9m x 9m (30ft x 30ft) or greater. These wider spacings were required to accommodate vigorous mango tree growth and minimise overcrowding over the orchard lifetime. Almost all mangoes grown at this time were the vigorous Kensington Pride variety. The development of mechanised hedging equipment, the registration of plant growth regulators, and improvements in orchard nutrition, irrigation and pruning practices have since enabled growers to maintain mangoes as smaller trees. Row and intra-row spacings have gradually reduced, resulting in increases in orchard tree densities per hectare.

Tree spacing is usually described as low, medium, and high density as follows:

Low density plantings (<200 trees/ha)

- Typically of size: 9m x 9m = 123 trees/ha (a)
- This spacing used in most Australian mango orchards established during the 1960s – 1990s.
- Mature trees are usually tall (>4m) and have wider canopies (>6m)
- Lowest canopy surface area to volume ratio
- Lowest establishment and annual input costs per hectare
- Takes the longest to reach full production
- Lowest yields

(a)

Medium density plantings (200 – 500 trees/ha)

- Typically of size: 8m x 6m = 208 trees/ha or 7m x 4m = 357 trees/ha (b)
- Spacing used in most Australian mango orchards established 1990s – present.
- Mature trees are usually <4m tall and canopies 4-6m wide.
- This density can be managed with common farm equipment and systems.
- Canopy growth managed using well-known techniques (hedging, PGRs)

(b)

High – Ultra high-density plantings (200 – 500 trees/ha)

- Typically of size: 6m x 3m = 555 trees/ha; 5m x 3m = 666 trees/ha; 4m x 2m = 1250 trees/ha (c)
- This spacing is uncommon, with highest densities only seen in some smaller commercial and research trials
- Mature trees are often short (<3m) and have narrow canopy width (<3m)
- Highest canopy surface area to volume ratio
- Highest establishment and annual costs
- Quickest to reach full production
- Highest yields
- Canopy growth is difficult to manage (particularly in vigorous varieties such as KP)

(c)

Before you start – Spacing rules of thumb:

- Individual mango trees at mature size will often grow up to 50cm tall and 50cm wide every year after hedging, so allow for annual growth.
- Farm machinery commonly requires a minimum of 2 – 2.5m accessible inter-row space at harvest time for reliable and unhindered access.
- To prevent excessive shading in fruit tree orchards, the desired tree height at harvest time should not be greater than 75% of the desired inter-row distance (e.g., if trees are expected to grow to 3.5m tall, then the minimum inter-row spacing should be 4.7m).

The decision on tree spacing is determined by four important considerations:

1. What is the mango variety?

Vigorous varieties such as KP have been difficult to manage in higher density systems due to their excessive vegetative growth rates. New advances in plant growth regulators (PGRs), may help control this tree vigour. Higher density systems suit less vigorous varieties such as Calypso®, R2E2, Honey Gold and Keitt, which may still grow up to 50cm tall and 50cm wide every year after hedging (Figure 6).

Figure 6. Calypso® variety planted at 1250 trees/ha at the DAF Walkamin Research Facility.

2. What is the target inter-row machinery access width?

Farm machinery commonly requires a minimum of 2 – 2.5m accessible inter-row space at harvest time for reliable and unhindered access (Figure 7). Inter-rows may need to be even wider in cases where particular farm equipment has extra space requirements (e.g. certain orchard sprayer set-ups). Allowances should be made to allow for annual lateral canopy growth, from hedging to harvest time, which makes the inter-row progressively narrower over the season.

Figure 7. Access for farm machinery should be considered when planning orchard layout.

3. What is the target tree harvest height?

If harvesting is to be conducted via hand-picking from the ground or by only using short picking sticks, then a harvest height of <3.2m is necessary. Harvesting trees >3.2m requires different picking practices which are generally slower and more expensive. These include the use of longer picking poles, cherry pickers or elevated harvest aid platforms. Taller trees require wider inter-rows to minimise shading.

4. What is the target tree harvest width?

The width of the tree is a more complex decision and is greatly influenced by the tree intra-row distance. If the trees are planted at wider distances along the tree row, then trees need to be allowed to grow to a greater width to ensure that they fill-out the hedge faces sufficiently to enable optimum fruiting. Trees planted at wider spacings (e.g., 5 – 6m) will need to be allowed to grow to wider widths/diameters to fill-out these hedge faces. Trees planted at close intra-row spacing (e.g., 2 – 3m) may only need to grow to 2 – 3m width/diameter to reach optimum fruiting dimensions (Figure 8).

Figure 8. R2E2 variety planted with 2 m spacing between trees in Bowen, Queensland.

Current Australian industry trends

New mango orchards in Australia are being primarily established as medium density systems usually between 200 – 400 trees/ha. Most of the new plantings include less vigorous varieties such as R2E2, Keitt, Honey Gold™ and Calypso®. The target tree heights at harvest within these new orchards are becoming increasingly shorter (often now around 2.5 – 3m) due to the economic and workplace efficiencies of harvesting low-hanging fruit. The target inter-row machinery access widths are fairly wide, often around 4 – 5m, which accommodates traditional wider spaced machinery, spray equipment and harvest aids. Target tree widths at harvest are also fairly wide, often around 3 – 4m.

Spacing opportunities

The trend towards much smaller tree heights provides new opportunities for increased planting density and the potential for increased orchard profitability. The first opportunity is through reductions in the target inter-row machinery access widths, which has been made possible by world-wide trends in the adoption of smaller and narrower orchard machinery/equipment for fruit tree management. The second opportunity is to reduce target tree widths at harvest by planting trees more closely within the intra-row. Mango trees are quite cheap to purchase from the nursery (<$20/tree) and planting at closer spacing reduces the time it takes for orchards to reach their optimum size, and hence maximum fruit production capacity. Research and farmer trials with varieties such as R2E2, Keitt and Calypso® have found with careful management, mature orchards can be maintained continuously and with high productivity, at narrow tree widths (2 – 3m).

Fact sheet 4: Trellis vs Hedge designs

Once the decision has been made to transition to a higher density planting, the next choice to consider is whether to opt for a hedged design (Figure 9) or install a trellis system (Figure 10). Both systems have advantages and disadvantages that growers should consider prior to finalising their decision. Table 4 outlines the advantages and disadvantages of trellis designs and Table 5 summarises the advantages and disadvantages of high density slim-hedge designs.

Figure 9. Slim-hedge design with R2E2 variety.

Figure 10. Trellis design with Keitt variety.

Table 4 Advantages and disadvantages of trellis designs vs slim-hedge designs

Advantages	Disadvantages
Provides strength and support to developing tree and resilience to cyclones and/or strong winds	Trellis infrastructure requires a significant initial capital investment
Narrow canopy allows greater light and spray penetration improving fruit quality, quantity, and blush	Trellis infrastructure may require maintenance and/or replacement over time
Fruit wall allows for quick and easy harvesting, reducing labour costs	Installing trellis infrastructure requires specialised skills and equipment
Facilitates higher planting densities per unit area; orchards begin producing commercial yields earlier	Specialist skills required to train and prune branches to desired trellis shape
Encourages tree to petition more resources towards fruit production in preference to vegetative growth; improved yield	High labour costs for training, bending and pruning branches until mature tree architecture is established; this can be 10+ years
Enables mechanisation of harvesting and automation of yield estimation	New technology with no long-term studies of trellis longevity and/or ongoing maintenance costs of aging infrastructure

Table 5 Advantages and disadvantages of slim-hedge designs vs trellis designs

Advantages	Disadvantages
Significantly lower initial capital investment costs as no trellis materials or installation costs required.	More prone to canopy gaps, as there is not any wire infrastructure onto which branches can be trained accurately
Quick and efficient hedging with mechanical hedger; significantly reduced pruning costs	Not as adaptable to mechanised harvesting; particularly with some fruit hanging inside canopy.
Low maintenance costs	Fruit hanging inside canopy likely to have higher pest pressure, lower blush and more skin blemishes.
Low complexity of management, particularly for specialist pruning and training skills	Yield forecasting less accurate as fruit hanging internally may be occluded from view
	Lower resilience to strong winds and/or cyclones

Fact sheet 5: Trellis design and construction

Trellis materials

Trellises consist of a system of supporting posts and wires, held tight by end assemblies (Figure 11). Most tropical tree crops are expected to have a lifetime of 20+ years, hence the trellises that support them need to be designed and constructed to last just as long.

In cyclone prone environments trellises should be strong enough to withstand cyclonic winds and support the estimated crop load. If you are considering installing trellising in a cyclone prone area it is recommended to consult the AgriFutures report 'Improving the Capacity of Primary Industries to Withstand Cyclonic Winds' available at https://www.agrifutures.com.au/product/improving-the-capacity-of-primary-industries-to-withstand-cyclonic-winds/ as this report contains detailed recommendations on trellis strength requirements and design & construction considerations for these areas (Drinnan *et al*., 2018).

Figure 11. Espalier trellis mango trees, part of the Planting Systems Trial at DAF Walkamin Research Facility. These trees were planted in 2013 at a spacing of 4m between rows and 2m between trees.

Posts

Material

Various materials can be used, such as timber, concrete or steel; however, treated pine posts are best for strength, durability, price and workability. Treated pine posts such as CCA (copper, chrome, arsenic) are ideal as they are resistant to the harsh environment where most mangoes are grown. For organic growers, alkaline copper quaternary (ACQ) treated posts may be a more suitable option. The Planting Systems Trial at Walkamin Research Facility on the Atherton Tablelands, Queensland, used H4 CCA treated 150 mm diameter posts. It is recommended to over-engineer trellis infrastructure to ensure durability for the estimated lifetime of the orchard.

Depth

Ideally, posts should be installed at least ⅓ of their height. "The force a post can resist without moving is equal to the square of its depth; therefore the depth of the posts is critical" (Drinnan *et al.,* 2018 p52). Soil type also influences resistance so sandier soils will require deeper placement and larger diameter posts than clay soils. Preferably posts should be rammed into undisturbed soil as this provides improved stability over posts that have been installed in augured and backfilled holes.

Orientation

Generally, trellises are installed in a north-south orientation to ensure the largest tree surface – the fruit wall – intercepts the most amount of sunlight possible. Site and locality characteristics should also be considered, including the slope, prevailing wind direction, shape of the block and sunlight intensity and duration. This may require the orientation to be adjusted from strictly north-south. Orchards in areas such as Darwin or Katherine in the Northern Territory should consider the potential implications of excess or extreme sunlight leading to sunburnt fruit and adjust row direction accordingly.

Height

The rule of thumb is that the height of trellises should be 67 – 83% the width of the rows, to maximise sunlight interception and avoid shading. It is recommended to consider management operations when deciding on final tree height as taller trellises must be stronger to support larger crop loads and are more difficult to prune, train, spray, thin and harvest. Workers may need to utilise ladders or elevating work platforms to access the top-most wires which brings with it WPHS concerns. Lower trellises enable closer row spacing but this may require specialised farm machinery and/or a greater capital outlay per unit area. The Planting Systems Trial at the DAF Walkamin Research Facility used 4.5m posts with 1.6m below ground and 3.2m above ground, six wires spaced every 0.5m, beginning at 0.5m above ground and the top wire at 3m. The inter-rows are 4m wide making the 3m finished height of the trees 75% the width of the rows. Ladders and elevating work platforms were necessary to undertake canopy management such as branch training and pruning on the top two wires and short picking poles were also required to reach fruit at harvest.

Wires

It is recommended to use 2.65mm diameter high tensile galvanised wire e.g., LifeWire. Larger diameter wires can be used e.g., 3.15mm, for added strength, however, this would increase costs.

Attachment

Attach wires to posts with long-life, galvanised, barbed “U” nails e.g., 40mm x 4mm. Ensure the “U” nail is installed slightly off vertical to the post wood grain to reduce the potential of splitting (a). Do not pre-drill holes for “U” nails to ensure a firm fit.

Trellis wires should be attached to the end assembly post, not the screw anchor.

(a)

Trellis End Assembly

Anchored post

The end assembly supports the tension and load placed on the trellis by the crop and wind. It is therefore critical to ensure that end assemblies are correctly installed and strong enough to support this load. Where anchored end assemblies are used in temperate industries such as viticulture, the recommendation is for end posts to be positioned at an angle of 65° to ensure the force placed upon it by the trellis wires acts to force the post into the ground (Figure 12). However, this may be difficult to achieve in a mango orchard, particularly where taller trellises may be desired, requiring longer, wider posts to support the weight of mango trees. The system installed at the Walkamin Research Facility consists of 4.8m posts with 150mm diameter erected upright at 90° with the top guide wire at a 45° angle to the screw anchors (Figure 13). The screw anchor must be positioned into undisturbed soil.

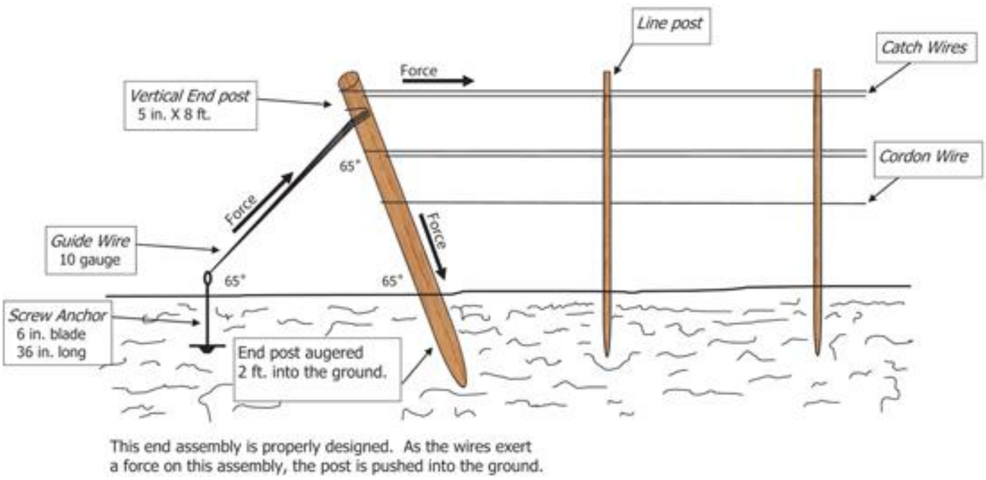

Figure 12. Trellis end post at 65° angle as used in temperate industries (Source: https://aces.nmsu.edu/pubs/_h/H331/).

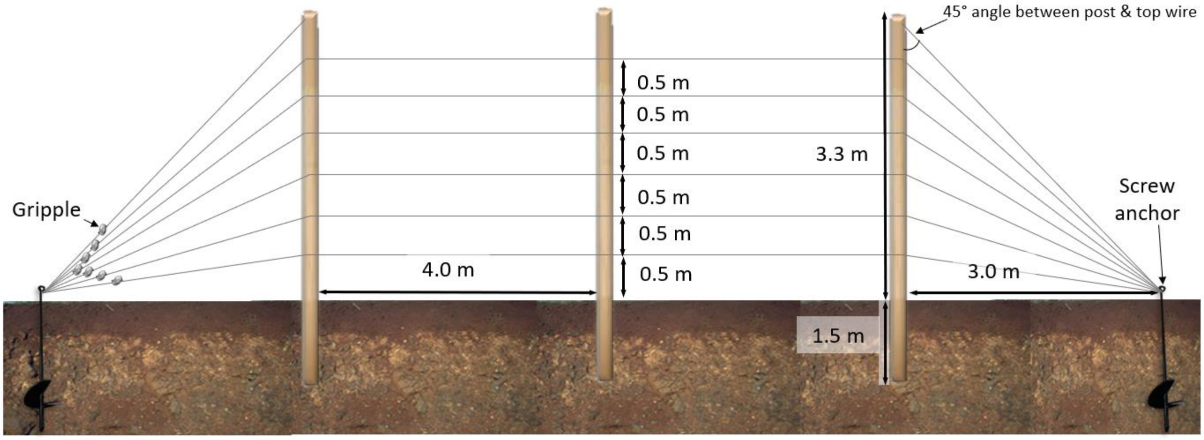

Figure 13. Trellis assembly at 90° angle as used in mango planting systems trial at Walkamin Research Facility

Estimated Costs

The costs for trellising were calculated for a hypothetical 1-hectare block (Table 6). The block specifications were:

- 18 rows x 138m long, 66 trees/row
- 4m inter-rows and 2m between trees = 1,188 trees/hectare
- 3m tall fence-style trellises with 6 x wires per trellis spaced 0.5m apart; starting at 0.5m from the ground

Table 6 Costs of materials and labour for one hectare of trellis infrastructure.

Item	Cost ($)	Quantity per row	Quantity per ha (18 rows)	Sub-Total ($)
175mm x 4.8m CCA H5 Pine logs	98.50	12	216	21,276
2.65mm long life, grow wire (m) 140m x 6 wires (per m)	0.17	840	15,120	2,517
1360 long single plate 20mm high tensile rod anchor	30.45	2	36	1,096
40mm x 4mm long-life galvanised, barbed staples (6/post)	0.08	72	1296	103
Medium gripple plus 2-3.25mm	2.60	12	216	561
Post installation (machinery and labour per hr)	195.00	1	18	3,510
Wire installation (labour per hr)	25.00	6	18	2,700
			TOTAL	31,763

Note: Prices are a guide only and were current as of January 2020.

(b) (c) (d)

Figure 14. Materials for trellis construction (b) gripples for attaching wires, (c) wire spinner and (d) example of screw anchor.

Fact sheet 6: Trellis pruning and training

What is tree training?

Tree training sets up the tree structure by pruning or bending limbs into position.

- Pruning trims or cuts branches or stems to encourage growth and removes dead, dying, and diseased branches or spent terminals
- Bending is the process of positioning branches and securing (tying) them in a horizontal or angled position.

Why do it?

Tree training develops a strong tree structure, slows growth, reduces vigour and helps bring a young tree into production earlier.

Types of training systems

There are two main types of trellis training systems - espalier and palmette (Figure 15). Espalier systems train branches horizontally along the wires (a & b) whereas with palmette branch training (c & d), the aim is to follow the natural growing habit of the tree into a fan or palm shape that fills in the trellis. Although this shape is two-dimensional, one of the main benefits of the palmette system (d) is that it is similar to how the tree naturally grows, requiring little bending and tying of branches with the tree filling the trellis quickly.

(a)

(b)

Figure 15. Trellis training systems – a & b espalier; c & d palmette

Pruning for trellis designs: Espalier training system

Mango trees grown using the espalier trellis method consist of a primary central leader branch that is trained vertically towards the top wire. Secondary lateral branches are trained horizontally along the wires of the trellis and attached to the wires with rubber ties or baling twine. The secondary lateral branches are pruned every 15 to 30cm to produce tertiary branches (Figure 16). For maximum productivity, it is critical to develop numerous tertiary branches along the secondary lateral branches, as these are the sites where flowering and fruiting occurs.

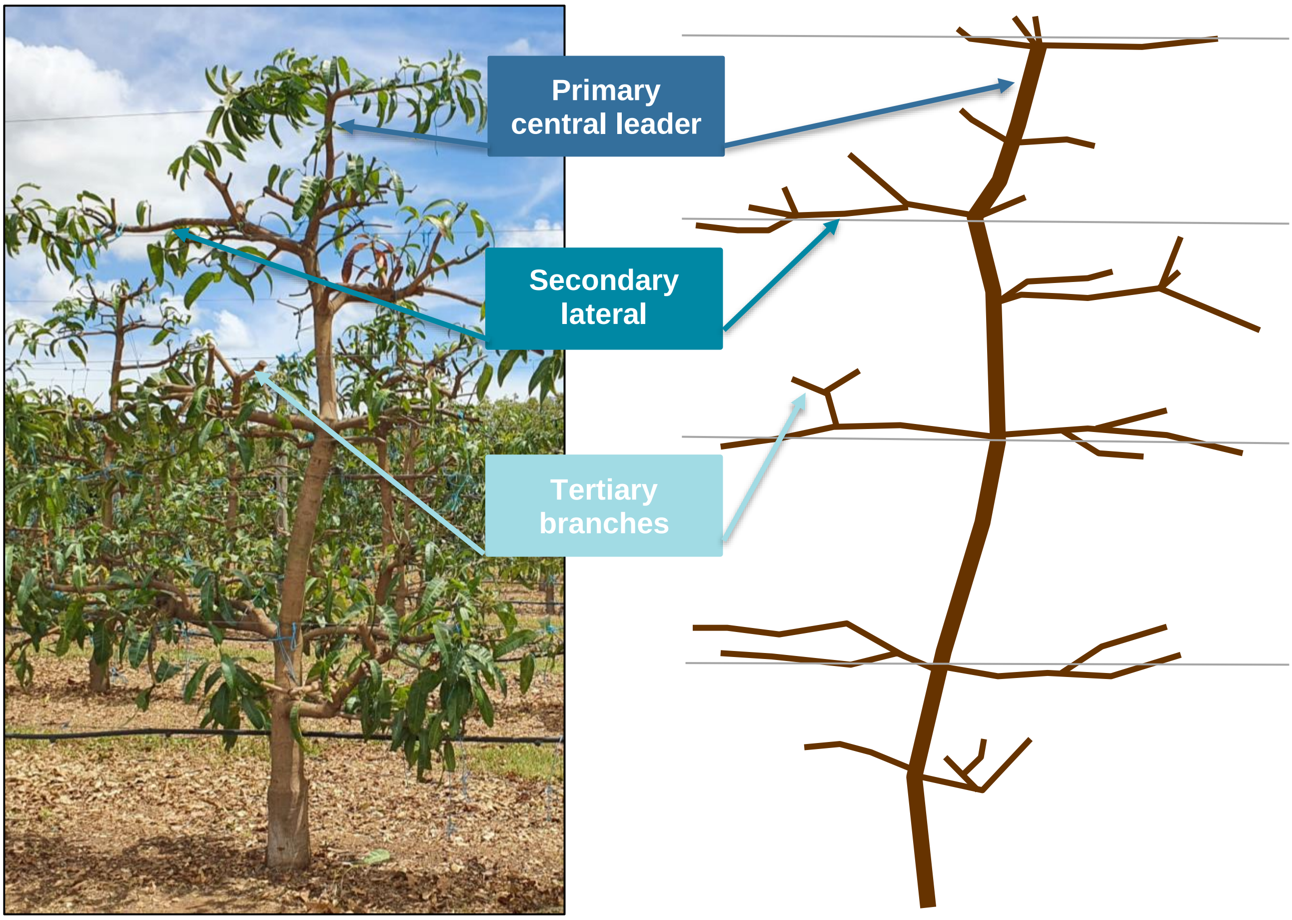

Figure 16. Espaliered mango trees consist of a central leader grown from the ground to the top wire; secondary lateral branches grown along the wires and tertiary branches produced by the secondary lateral branches that produce flowers and fruit.

Equipment required

To prune and train espaliered mango trees you will need:

- A good pair of secateurs
- Rubber ties for securing branches to wires (a). Rubber ties stretch which reduces the risk of constricting branch growth
- Baling twine or similar for branch training tasks where rubber ties are unsuitable (b)
- Scissors or a knife for cutting twine. Alternatively, secateurs can also be used.
- A ladder. This will only be required once the trees have reached the higher trellis wires

(a) (b)

The first prune

The first prune should be above the first wire to encourage branching to occur above the wire. The aim is to always bend limbs down to a wire, not up, as bending branches reduces vigour. Pruning above the wire ensures branches are bent down to the wire. Ideally the first prune will be above the wire and below a whorl of leaves, where there are a minimum of three or more evenly spaced leaves with axillary buds present. Pruning here will stimulate the buds to form branches that will become the single leader and lateral branches (Figure 17).

If there are no suitable options immediately below a whorl of leaves, trees may be pruned immediately above a whorl. This will result in multiple branches initiating from the same point which could become a weak junction. However, it will provide multiple options for selecting the laterals and central leader. The main aim is for the first prune to be **above** the first wire.

Remove any shoots that develop below the first wire and below the graft union (Figure 18).

Figure 17. It is best to wait for the tree to grow above the first wire before completing the first prune. Once there are three or more evenly spaced leaves above the first wire, prune above the topmost leaf, ensuring the axillary bud is retained. Avoid pruning immediately above a whorl of leaves (if possible) or below the wire.

Figure 18. Remove branches below the first wire or emanating from below the graft.

The first limb training

The first limb training should be completed after flush has matured. Young flush is delicate and can easily snap, so it is important to wait until flush is fully developed. Select the most vigorous branch to be the central leader, preferably a branch that emanates from the middle of the tree (c). The central leader can be left free growing if it is growing correctly or baling twine can be used to encourage upright growth towards the second wire (d).

(c)

(d)

Select one to two branches on each side of the central leader to become the secondary lateral branches. Attach these to the wire using rubber ties or baling twine (e). Do not tie the branches too tight. The plant is *encouraged* to grow along the wire; not forced. Tying it back too tightly restricts movement and growth and can cut into the branches. If there are two lateral branches on each side, tip one lateral branch at 15cm and the second at 30cm to produce the tertiary branches on each side of the central leader. If there is only one secondary lateral branch on each side, tip each at 15cm (f).

(e)

(f)

Subsequent limb training

Once the lateral branches have produced shoots and they have hardened off, choose one to continue along the wire as the lateral (g) and tip-prune the remaining branches to form the tertiary branches (h). Remove water shoots and vertically growing shoots. The preference is for downward or outward facing tertiary shoots.

When the primary central leader has grown above the second wire, prune again to produce lateral shoots and follow the same process as for the first wire (i).

(g)

(h)

(i)

Annual maintenance

After harvest, prune tertiary branches back to the first or second growth flush from the lateral branch. In older systems, a hedging machine can be used first, to remove most of the biomass, however hand pruning will still be required to complete the pruning process.

Inspect ties and baling twine regularly to ensure they are not restricting plant growth or cutting into branches and remove any that are no longer required.

For a video on how to prune and train espaliered mango trees please visit: https://tinyurl.com/veuwwyup

Pruning and training once tree shape is established (5+ years)

After the trees are mature and all laterals and sub-laterals have been established, pruning is required twice per year – once, after harvest to bring branches back to the sub-laterals and remove water shoots (j) and once after flowering and fruit set to remove unfruitful branches and control excessive vegetative growth. Avoid removing too much foliage close to harvest as this can cause sunburn on the fruit (Drinnan *et al.*, 2018).

(j)

Limb training: when to do it?

Pruning encourages a heavy vegetative response and should be conducted regularly over the first five years to give the desired branching structure, as quickly as possible. If pruning is not conducted regularly then a lot of vegetative growth may be removed (and wasted) when cutting branches back to achieve the desired 15-20cm branch length. Avoid training branches before flush has hardened off, as the developing stems and branches are fragile and prone to breaking.

Training fundamentals

Lateral branches should be kept smaller than the leader. The main branch can become starved if the subsequent branches become too dominant or vigorous. A good rule of thumb is that laterals and sub-laterals should be no larger than ½ to ⅓ the diameter of the branch from which it originates. Leave companion branches to replace dominant branches over time with ones that are less vigorous. Gravity will assist with maintaining horizontal branches over time, especially once trees start to flower and fruit.

Remember to check rubber ties and strings regularly to ensure they are not cutting into developing branches (k). Remove or replace ties before they cause damage, as this can provide entry points for disease.

(k)

Fact sheet 7: High-density hedge (slim hedge) design, pruning and training

What is a slim hedge?

Hedges are defined by allowing neighbouring tree canopies to touch along the intra-row, achieving a wall of vegetation/fruit along each lateral face (Figure 19, a). Hedge systems may occasionally (e.g., every 1-3 years) have the intra-row tree canopies pruned back between neighbouring trees, if canopies become entangled or too dense and have internal vegetation removed every four or so years. However, this may not be necessary with good orchard hygiene practices and regular hedging. Mango hedge systems are not a new concept and older wide-spaced trees have often been allowed to grow into hedges. Wide-spaced hedge designs, however, are often characterised by wide canopy widths, resulting in large voids within the trees, which can harbour pests and diseases and are less efficient for pesticide management practices. The new high-density hedge systems are characterised by very narrow canopy widths (Figure 19, b). These hedge systems are known as 'slim-hedges'. They have lower row canopy volumes/ha but higher canopy surface area/ha than low density systems.

For a video on slim hedge orchard designs and considerations please visit: https://tinyurl.com/ntnajx4z

(a) (b)

Figure 19. Example of a slim hedge orchard planted in the 1990s at Bowen (a) with average yield of 30-38 tonnes/ha. Slim hedge orchards are characterised by narrow canopy widths of <3m (b).

Slim-hedges have the following advantages over wider-spaced hedge or conventional systems:

- Greater orchard canopy surface area/ha provides greater photosynthetic capacity/ha.
- Greater canopy surface area/ha means more sites for flowering and fruit production, resulting in higher yields.
- Lower tree volume/ha requires less pesticide spray volume/ha thus reducing pesticide input costs and improving efficiencies
- Lower tree volumes/ha reduces harbourage sites for pests and diseases.
- Improved harvesting efficiency – fruit harvested from short, narrow trees, are more easily and rapidly picked from the ground, either by hand or with short picking sticks than larger trees
- Efficient use of site resources and input costs

(c)

Figure 20. Many growers now use harvest aids when picking (c). This is an example of a self-propelled harvest aid. The small Keitt mango trees in this orchard are fast and easy to pick and the harvest aid applies a detergent/neutraliser such as Mango Wash® to protect fruit and neutralise sap, before depositing the mangoes into a half-tonne bin.

Principles of slim-hedge orchards

- Tree canopies are maintained as narrow hedges, no more than 2 – 3 metres wide
- Trees are planted no more than 2 – 3 metres apart within the row
- Trees are regularly tip-pruned during the establishment years to maximise the number of tertiary fruiting terminals
- Mechanical hedging along the row is implemented early (from approximately year 4 onwards) to maintain the canopy at no more than 2 – 3 metres wide. Mechanical pruning is used to remove only one year of growth to 're-set' the tree each year (Figure 21).
- Maximum tree height is reached by year 6 or 7 and is maintained with post-harvest mechanical pruning
- Once trees have established a continuous hedge along the row, pruning between trees is ceased

Figure 21. Post-harvest mechanical pruning (d) is a common practice in Australian mango orchards.

Considerations when planning a slim-hedge orchard

- Sprinkler irrigation systems may be less suitable to high density slim hedge designs due to their smaller canopies and dripline. Consider discussing alternative options - such as dripper systems - with your irrigation supplier.
- A narrower canopy means a less-powerful spray rig is needed to achieve adequate canopy coverage. Alternatively, operators can increase tractor speed when spraying, resulting in savings on labour, chemical and running costs.
- If the hedge face has gaps between trees, trial techniques such as pruning or cincturing to encourage branching to fill gaps. Branches may also be trained using weights or tied to neighbouring trees to encourage growth to fill voids.

Can you retrofit existing low-density orchards?

Retrofitting low density orchards by inter-planting between existing trees is possible but is not without challenges (Figure 22). The newly planted, young trees compete for light and site resources with the larger, established trees and may suffer from higher pest pressure, resulting in poorer thrift. Instead, it is worth considering transitioning to a high-density orchard using a staged approach a block or two at a time. This allows trialling higher planting densities on a small scale to assess the management requirements and economic benefits before implementing it across the entire farm. It also maintains an income stream from existing blocks while the newer high density blocks reach maturity. Ongoing renewal of orchards every decade or two, also means new mango varieties can be incorporated into the farming system.

(e)

Figure 22. Low-density orchards such as this one are being phased out as the Australian mango industry transitions to higher density planting systems. This is an example of an older orchard where a tree has died or been removed, leaving a large gap between trees (e). Retrofitting low density orchards by inter-planting young trees within rows or adding new rows between existing rows, would present management and productivity challenges. Instead, consider a staged approach where old trees are removed a block at a time and replaced with new blocks of higher density plantings.

References

Bally, I.S.E. and Ibell, P.T. (2015). Improvement of mango tree architecture. Acta Horticulturae, 1075, p59-64.

Bally, I.S.E., Ibell, P., Mahmud, K., Wright, C., Mizani, A., and Wilkie, J. (2020). Benefits of intensive production systems in mango. Acta Horticulturae, 1281, p 493-498

Bennett, D. M., and Dickinson, G.R. (2021). Economic case study of intensive mango systems: A comparison of the profitability of conventional (low, medium and high density) and trellis (high density) mango canopy systems in north Queensland based on early trial results. https://crcna.com.au/resources/publications/economic-case-study-intensive-mango-systems. 28pp.

Crawford, A. (2016). Final Report – Future Orchards 3. AP11017. Hort Innovation, 24pp

Department of Primary Industries and Fisheries (1999) Mango Information Kit. Agrilink, your growing guide to better farming guide. Eds. Kernot I, Meurant, N., Holmes, R., MacLeod, N., Fullelove, G. and Bally, I. Manual. Agrilink Series QAL9903. Department of Primary Industries, Queensland Horticulture Institute, Brisbane, Queensland.

Drinnan, J., Wiltshire, N., Diczbalis, Y., Holden, P., and Thompson, M. (2018). Improving the capacity of primary industries to withstand cyclonic winds. AgriFutures Australia, New South Wales.

Hort Innovation. (2017). Mango Strategic Investment Plan: 2017-2021.https://www.horticulture.com.au/globalassets/hort-innovation/levy-fund-financial-and-management-documents/sip-pdfs-new/hortinnovation-sip-mango-2017-2021-dec2017.pdf

Menzel, C. M., Le Lagadec, M. D. (2017). Can the productivity of mango orchards be increased by using high-density plantings? Scientia Horticulturae, 219, 222-263. https://doi.org/10.1016/j.scienta.2016.11.041

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