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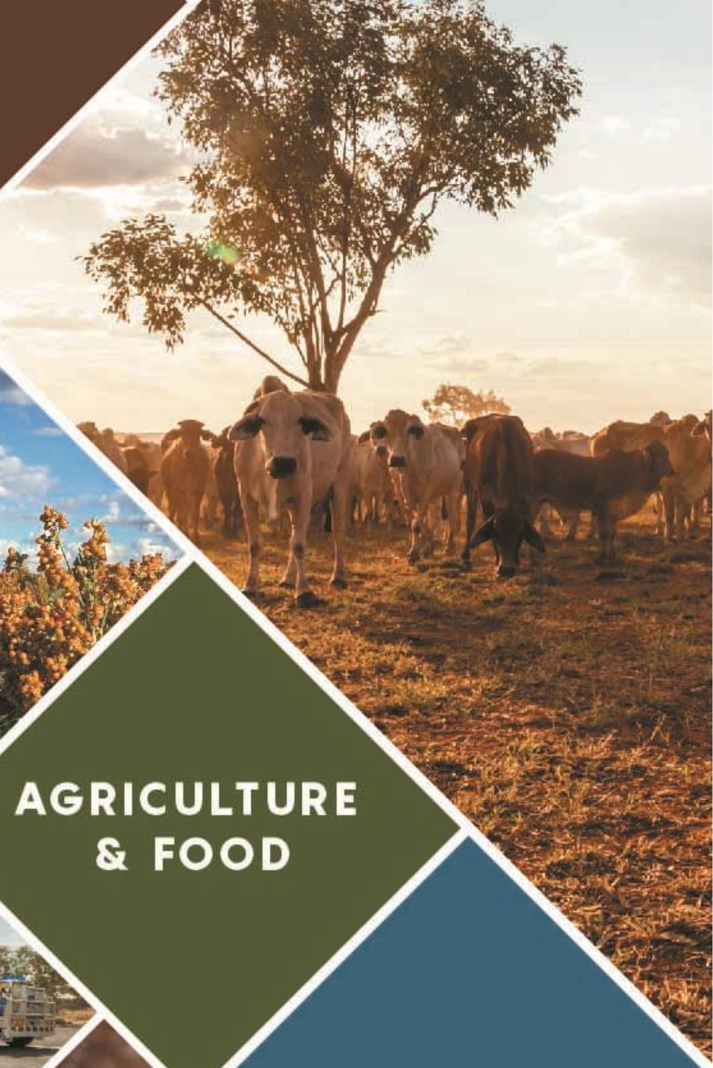

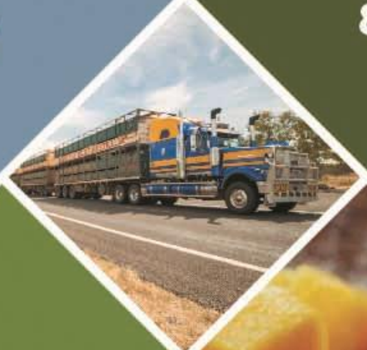

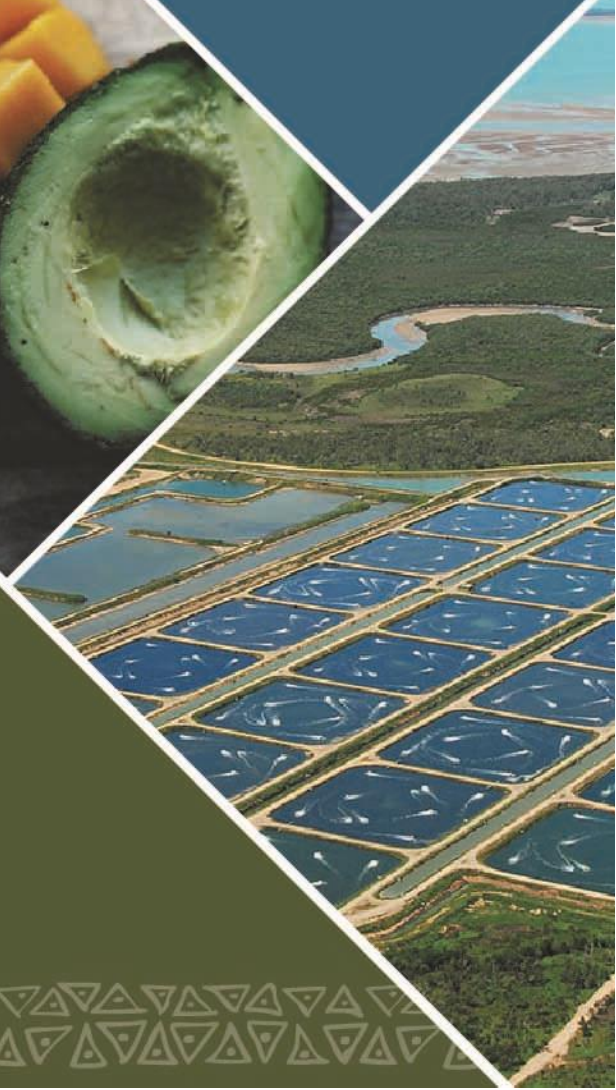

Economic Case Study of Intensive Mango Systems

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

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CRCNA

DEVELOPING NORTHERN AUSTRALIA

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Additional information on management inputs, costs, projected yields and prices was provided by the four project partners, mango growers, industry stakeholders and from published reports. We would also like to thank the businesses, Blue Sky Produce, Blushing Acres, Tableland Fertilisers and Leonie Wittenberg Crop Monitoring for their assistance.

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Disclaimer

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Table of contents

List of Tables

List of Figures

Acronyms

AMIA	Australian Mango Industry Association
APAL	Apple and Pear Australia Ltd
CCA	Copper chrome arsenate (CCA) treated timber is wood that has been treated with a preservative containing copper, chromium, and arsenic
CRCNA	Cooperative Research Centre for Developing Northern Australia
DAF	Department of Agriculture & Fisheries (Qld)
FORM	Fuel, oil, repairs, maintenance
IRR	Internal Rate of Return
KP	Kensington Pride mango variety
ML	Megalitre
NMBP	National Mango Breeding Program
NPV	Net Present Value
PST	Planting Systems Trial
WRS	Walkamin Research Station

Project Partners

Queensland Government

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Summary

This economic case study compares discrete farm level investments in conventional low, medium and high density canopy systems and a trellis high density canopy system for mango production in north Queensland. A key priority for the Australian mango industry is to increase industry productivity through increased yields and reduced input costs. The adoption of high density orchard systems by other tree crops has successfully improved the profitability of these industries and there is potential for these systems to also improve profitability of the mango industry. Early results from the six-year old Department of Agriculture and Fisheries (DAF) mango Planting Systems Trial (PST) at Walkamin have supported this concept, with higher density planting systems producing higher yields per hectare sooner and with higher input efficiencies than conventional planting systems.

This case study aims to determine whether the extra investment required to implement medium or high density mango orchards is likely to return a higher gross margin, compared to conventional low density orchards, using the B74 (Calypso®) variety. Data were sourced from the DAF Planting Systems Trial at Walkamin, researchers, growers, agribusinesses and industry stakeholders. Profitability was assessed using gross margin. Three key outcomes were identified.

The first key outcome was the calculation of establishment costs/hectare for the four canopy systems. These costs/hectare increased with increased planting density and with additional trellis infrastructure as follows; conventional low density ($10,491), conventional medium density ($15,853), conventional high density ($35,487) and trellis high density ($66,647). The establishment costs incorporated land preparation (boom spraying, slashing, cultivation/ripping, levelling), irrigation (pipes, sprinklers, connectors, materials, installation labour, proportion of pump and pump shed costs), planting (cost of trees, pre-plant lime application and planting labour) and trellis infrastructure (materials and installation).

The second key outcome was that higher density orchards, achieve much higher annual gross margins/hectare (difference between annual gross revenue and annual variable costs) than lower density orchards. (Note: the gross margin did not include capital expenditure or fixed costs). These higher annual gross margins/hectare were clearly evident at age 6 years based on the most recent data from the DAF Planting Systems Trial with results as follows; conventional low density ($15,560), conventional medium density ($34,205), conventional high density ($85,305) and trellis high density ($55,128). These results were then modelled to estimate annual gross margins/hectare when orchards had reached their maximum steady-state canopy size from age 11 years onwards. These figures were even more pronounced for the high density systems at the maximum canopy size, with results as follows; conventional low density ($21,138), conventional medium density ($42,738), conventional high density ($92,068) and trellis high density ($108,514).

A key driver of this increased profitability for the high density systems, is the proportionally higher and earlier fruit yields per hectare that have been achieved with increasing intensification. Estimated fruit yields/hectare/year at maximum canopy size were; conventional low (18.2 t), conventional medium (32.6 t), conventional high (58.7 t) and trellis high (65.9 t). Fruit quality was not influenced by canopy system design, based on the early results from the Planting Systems Trial. A summary of annual yields and gross margin/hectare for the four canopy systems at full production is presented in Table 1.

The third key outcome was that the cumulative nett cash flow/hectare (the accumulation of annual gross margin/hectare each year) became positive across all four systems at a relatively young age (4 years for conventional high density, 5 years for conventional low and medium density and 6 years for trellis high density), but then rapidly accelerated in the systems with increased planting density and intensification. Cumulative nett cash flow/hectare by age 11 years was calculated as; conventional low density ($120,000), conventional medium density ($254,000), conventional high density ($617,000) and trellis high density ($495,000).

The adoption of higher density planting densities requires a higher level of investment during establishment and the first 10 years; however these are rapidly recouped by the higher revenues achieved by increased yield per hectare. Additional benefits of high density systems also include improved cyclone resilience, spray efficiency and greater application for new technologies such as automation and robotic harvesting.

Cautionary Note: The findings of this report rely greatly on the modelling estimates calculated from the early results (0-6 years) of the DAF Planting Systems Trial at Walkamin. It is possible that as these orchard canopy systems mature over time, future yields may respond differently than has been predicted by this modelling. It is recommended that this economics case study is updated as new data becomes available. 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 all factors specific to their situation before progressing.

Table 1. 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 ($/ha)					
Nutrition		1,410	2,106	3,132	3,016
Pest management		3,984	5,415	3,478	2,913
Disease management		4,560	6,366	3,179	2,706
Weed management		526	754	876	876
Irrigation		634	1,161	1,576	1,404
Canopy management		1,990	3,587	7,706	6,346
Harvesting		2,933	4,694	8,449	9,485
Packing		11,726	20,806	37,245	41,782
Freight to market		4,391	7,867	14,160	15,895
Commissions & Levies		6,283	11,259	20,272	22,747
Total variable costs ($/ha)		**38,437**	**64,015**	**100,073**	**107,170**
GROSS MARGIN (Total income – Total variable costs)		**21,138**	**42,738**	**92,068**	**108,514**

Introduction

Maintaining profitability in an environment of increasing costs is a key challenge facing the Australian mango industry. Low and variable production continues to hamper competitiveness and has impacted on the expansion of exports. A key priority for the Australian mango industry is to increase industry productivity per hectare through increased yields and reduced costs (Hort Innovation, 2017). Production volumes average around 65,000 tonnes annually, the industry aspires to increase annual production to over 82,000 tonnes by 2022 (Hort Innovation, 2017, 2020). To achieve these targets, improved productivity is essential, however this is challenging with conventional planting densities of less than 300 trees per hectare. 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 trellising 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.

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).

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 in excess of 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; Fealy, 2017; Menzel & Le Lagadec, 2017) and greater cyclone resilience (Drinnan *et al.* 2018).

The Australian mango industry has experienced a slow shift towards increased planting density over the past 20 years. Semi-dwarf varieties such as Calypso® and Keitt, have been commercially planted at densities up to 357 trees/ha and R2E2 up to 555 trees/ha. A study by Drinnan *et al.* (2018) found that mangoes grown at Mareeba under a high-density trellis system (666 trees/ha) also showed good applicability to this system.

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 need additional labour for pruning and training. In new systems, these costs are challenging for growers to accurately estimate, making it difficult to make informed decisions about moving to higher density designs.

This report is a case study of a range of intensive mango systems that will assist growers when establishing new mango plantings to choose which orchard management design is most suitable to them. Study data was sourced from the DAF Planting System Trial (PST), the Australian mango industry, growers, industry stakeholders and published reports. The case study compares conventional mango planting systems at three different densities - low (207 trees/ha), medium (408 trees/ha) and high (1,242 trees/ha) and one trellised planting system at high density (1,188 trees/ha). The mango variety B74 (Calypso®) has been selected as the focus variety for this study.

Methodology

Economic spreadsheet tool and data sources

The economic analyses were conducted using an economics calculator file developed in Microsoft Excel by Fred Chudleigh, DAF Economist. This DAF calculator tool was first developed in the 1990s and has been updated and adapted regularly to conduct economic studies for a wide range of agricultural applications. The economics calculator file includes multiple linked spreadsheets. These included individual input base costs (materials, labour, FORM etc), a calculator sheet where establishment and annual variable costs were calculated based on assumed best-bet practices for each canopy system, and gross revenue based on fruit yields, quality grades and price per grade for each year up to an orchard lifetime of 30 years. This 30 year lifetime is equivalent to the approximate economic and investment life of many similar orchard investments. These data were then used to calculate gross margin and cumulative nett cash flow per hectare for each orchard management system over the orchard lifetime.

The expenditure and revenue figures produced within this case study were calculated from many different sources. Input costs of materials, machinery and labour and recommended work/application rates (at 2020 dollar values) were collected from; existing DAF economic records, the Planting Systems Trial, the Australian Mango Industry Association, mango growers, private agricultural consultants and published reports. Data on fruit yields and quality, canopy surface area and canopy volume per hectare for each of the four canopy systems were collected from the Planting System Trial to age 6 years. These data were then modelled to estimate expenditure and revenue figures from age 6 years onwards, based on the assumption that fruit yields per hectare and most input costs would continue to increase proportionally with increase in canopy size, until each canopy system grew to its maximum target dimensions. Once this target size was reached (between 10 to 11 years for the four systems), expenditure and revenue figures were assumed to remain constant.

Canopy system treatments

Four canopy management systems were investigated in this study. The tree and row configuration within these four orchard management systems was based on a subset of those used within the DAF Planting Systems Trial at the Walkamin Research Facility (WRS), established in 2013 (Bally *et al*., 2020). The inter- and intra-row tree spacings used were conventional low (8 x 6 m = 207 trees/ha), medium (6 x 4 m = 408 trees/ha) and high (4 x 2 m = 1,242 trees/ha) density and one trellised system at high density (4 x 2 m = 1,188 trees/ha).

The tree number/ha for each system was calculated by the number of trees which could be placed into a ‘standard’ 1 hectare block (72 m wide x 139 m long) which could practically fit these inter- and intra-row spacings. The trellis system also required additional space within the ‘standard’ 1 hectare block for the establishment of tie-down anchors for the trellis system, resulting in a small reduction in tree number/ha. The DAF Planting Systems Trial included three mango varieties; B74 (Calypso®), Keitt and NMBP1243. The variety B74 (Calypso®) was chosen as the subject for this case study.

Table 2. Key parameters and assumptions used in the economic case study

Variety	B74 (Calypso®)				
Productive life of trees	30 years				
Orchard layout	Trees/ha	Tree spacing (m)	Inter-row spacing (m)	Rows/ha	Trees/row
Conventional low density	207	6	8	9	23
Conventional medium density	408	4	6	12	34
Conventional high density	1,242	2	4	18	69
Trellis high density	1,188	2	4	18	66

Whole-of-farm assumptions

The establishment figures include all costs required to establish the orchard blocks to the stage of tree planting and orchard infrastructure construction. These costs include: Land preparation, irrigation materials and establishment, pre-plant fertiliser and chemical application, trees, trellis materials and construction, labour, and machinery costs (e.g. FORM – fuel, oil, repairs, maintenance). Production costs then accrue over the orchard lifetime. Variable costs (those costs that vary with the level of production) in this case study include weed, insect and disease control, fertiliser, irrigation, training, pruning and thinning, picking and packing, freight to market, marketing and levy costs, labour and machinery costs. The machinery operation costs were calculated using tractor size, FORM and work rate. Labour was also included in the costs for each farm operation and was calculated using the work rate multiplied by an hourly rate of $27.00.

Capital costs such as land and buildings have not been included, nor have overhead costs such as rates, insurance, living costs, interest and farm manager costs. These costs have been excluded from the case study as these have been assumed to be approximately the same between the four management systems.

Modelling canopy size over orchard lifetime

Actual canopy architecture growth data from the Plating Systems Trial for ages 0 to 6 years were used in conjunction with the target maximum canopy architecture size to predict annual increases in tree canopy surface area and tree volume for the four canopy management systems (Figures 1 and 2). These parameters were then used to extrapolate actual data from age 0 to 6 years for revenue (fruit yields) and variable costs (nutrition, insect, disease management, irrigation, pruning, picking and packing) across all four canopy systems for the lifetime of the orchard.

Key growth assumptions made for these trees based on standard Calypso® growth rates were; (1) terminal top shoots will produce approximately 60 cm vertical growth per year and (2) terminal side shoots will produce approximately 30 cm horizontal growth per year. Key canopy management assumptions were made for these trees based on standard commercial practices. For trees that have not reached mature size; half of annual growth will be pruned off every year (30 cm top or 15 cm each side). For trees that have reached mature size; (1) pruned canopy height is 3.1 m, (2) pruned canopy width for low & medium density trees is 3.2 m, high density is 1.2 m and trellis is 0.5 m, (3) pruned intra-row width (between trees in a row) for low density is 3.2 m, medium density is 2.8 m, high density is 1.6 m and trellis is 2 m (no gap), and (4) canopy bottom height is 0.9 m for low, medium and high density and 0.3 m for the trellis system.

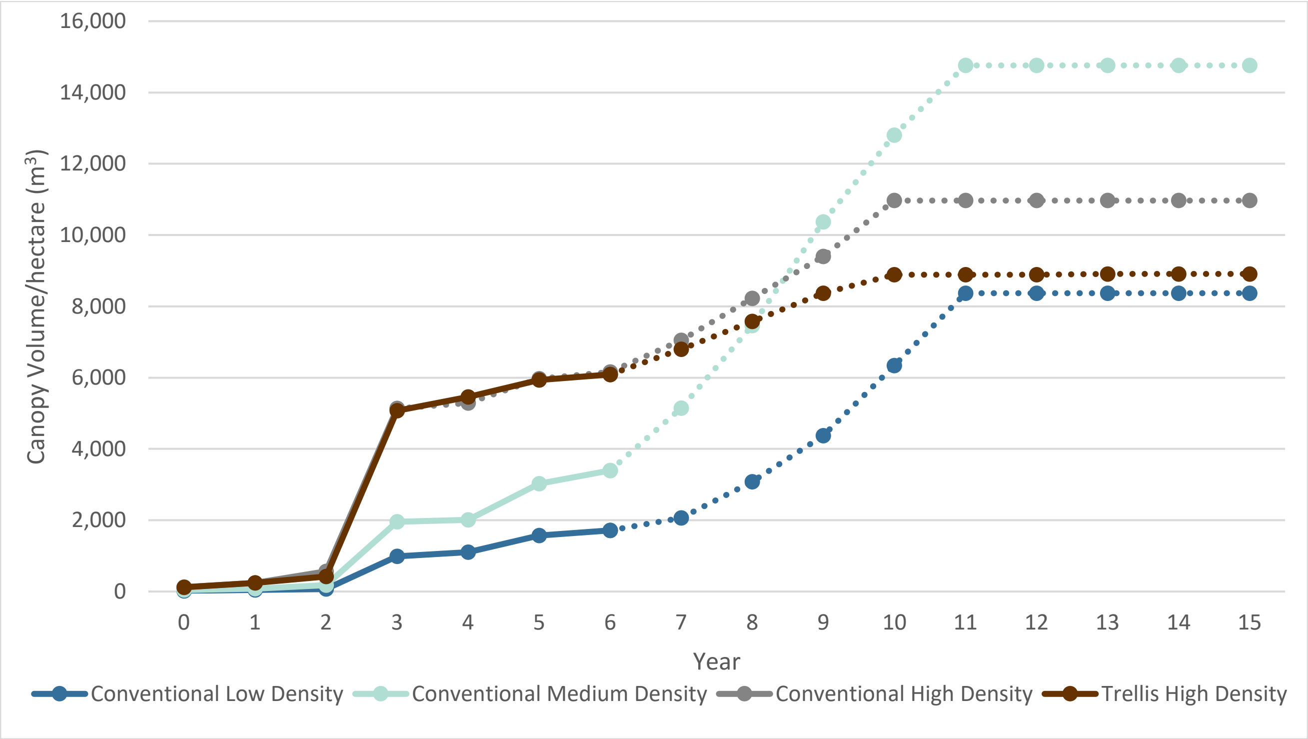

Figure 1. Maximum tree canopy volume per hectare. Data in solid lines were based on data from the PST. Data in dotted lines were estimated and assumed to hold steady at year 11 levels for the remaining life of the orchard.

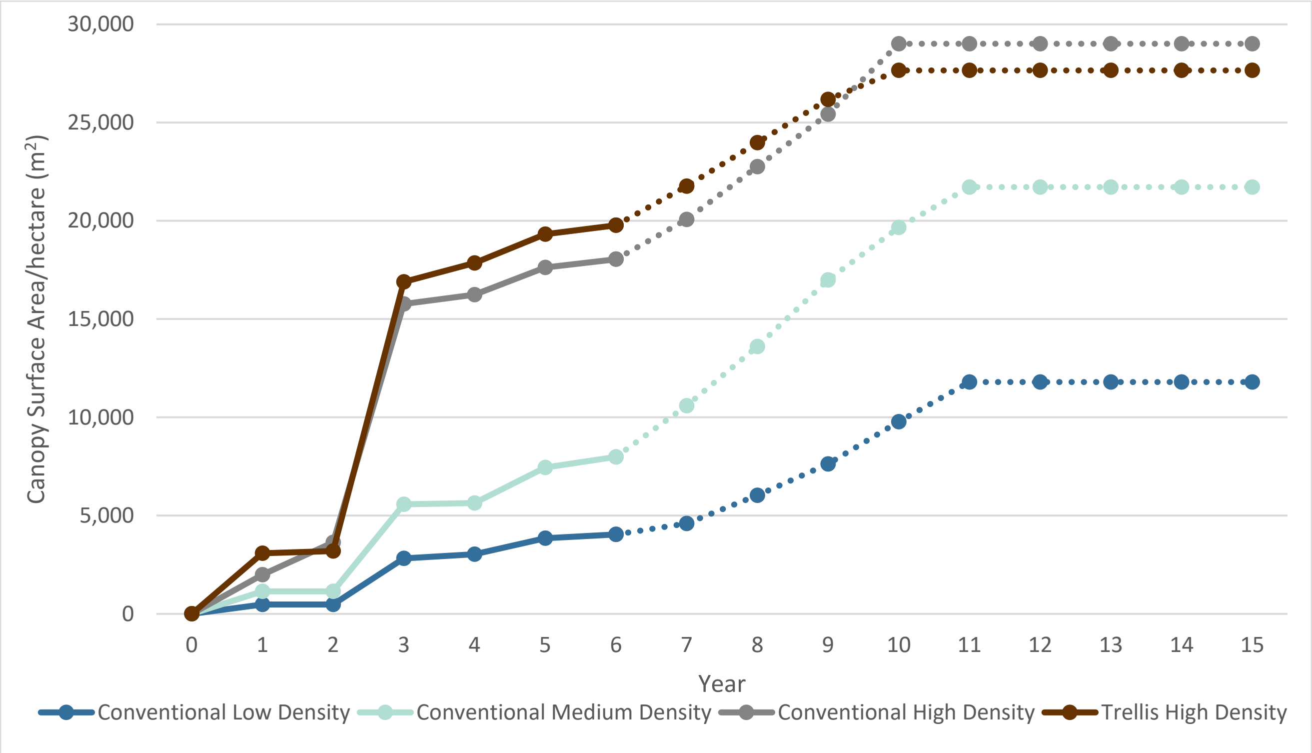

Figure 2. Maximum tree canopy surface area per hectare. Data from in solid lines were based on data from the PST. Data in dotted lines were estimated and assumed to hold steady at year 11 levels for the remaining life of the orchard.

Revenue calculations

Annual revenue was calculated from actual and predicted yield and quality grade proportions, at average market prices (2017-2020) per grade for Calypso® fruit. Total fruit yields (kg/tree and t/ha) were based on results from the four orchard management systems within the DAF Planting Systems Trial for years 0 – 6 and estimated yield from 7 years onwards (Table 3). Estimated yields were calculated by determining the difference between the orchard canopy surface area/ha at age 6 years and the projected canopy surface area/ha at maximum canopy size (Figure 2). Maximum yield per hectare was achieved at a tree age of 11 years for the conventional low density system and 10 years for the other three systems. Yields from year 11 onwards have been maintained throughout the residual orchard lifetime. (Cautionary note. There is some uncertainty that despite the trend of increasing high early yields of the high density systems from ages 0-6 years, there is some suggestions that these trees could become crowded and less productive over time and yields may reduce, however there is currently no documented information to support this theory).

Harvested fruit was estimated at 95% of total fruit yield, with a further 1% of harvested fruit rejected in the pack-line as non-saleable. Saleable fruit grades and prices were then estimated, with fruit allocated to four categories (premium, 1st class, 2nd class and processing) at proportions similar to Calypso® variety averages of 77%, 14%, 4% and 4% respectively. Prices for these four grades were determined based on average industry figures over the past 3 years, for Calypso® fruit at $4.00/kg, $2.00/kg, $1.57/kg and $0.50/kg respectively. It was assumed that there were no differences in quality and therefore no difference in prices for each of the four planting systems. This is based on preliminary results from the Planting System Trial that show no significant difference in quality between treatments.

Table 3. Total field yield per tree (kg) and per hectare (tonnes) for each of the planting systems

Age	PST year	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	
		Kg/tree	t/ha	Kg/tree	t/ha	Kg/tree	t/ha	Kg/tree	t/ha
0	2013	0	0	0	0	0	0	0	0
1	2014	0	0	0	0	0	0	0	0
2	2015	0	0	0	0	0	0	0	0
3	2016	11.1	2.3	9.1	3.7	11.9	14.8	7.8	9.3
4	2017	37.1	7.7	35.2	14.4	27.1	33.7	28.2	33.5
5	2018	46.3	9.6	43.0	17.5	32.2	40.0	34.4	40.9
6	2019	58.0	12.0	58.6	23.9	43.1	54.2	35.3	41.9
7	2020	66.0	13.7	64.0	26.1	45.0	55.9	41.0	48.7
8	2021	73.0	15.1	69.0	28.2	46.5	57.8	46.0	54.7
9	2022	79.0	16.4	74.0	30.2	47.0	58.4	50.0	59.4
10	2023	85.0	17.6	79.0	32.2	47.3	58.8	55.5	66.0
11+	2024	88.0	18.2	80.0	32.6	47.3	58.8	55.5	66.0

Note: Yield figures from 0-6 years are actual figures collected from the Planting Systems Trial, whereas yield figures from year 7 onwards were estimated.

Establishment costs calculations

Establishment costs for a conventional mango farm comprises costs such as land preparation, purchase and installation of irrigation equipment (including pump and associated infrastructure), pre-plant fertiliser and weed control operations, the cost of trees and planting. Trellis orchards require the same range of establishment costs as conventional orchards, but with the additional cost of the purchase and installation of the trellis infrastructure. The trellis design used in this case study was the same as that used in the DAF Planting Systems Trial, with details as follows for establishment on the 'standard' one hectare block:

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

Variable production costs calculations

Nutrition

Nutrition costs included the materials and application costs of fertilisers and the plant growth regulator paclobutrazol, based on the requirements for growing B74 mango trees in the Mareeba/Dimbulah region. Fertilisers used in this case study included Lime, Gypsum, Ozcal™, Organibor®, Nitrophoska® Special, Solubor®, and Potassium Sulphate (See Appendix 1). Lime (pre-plant application only) and Gypsum (annual applications) were applied by spreader. Ozcal™, Organibor®, Nitrophoska® Special, and Potassium Sulphate were hand-applied to young trees (aged 0 to 4 years) and then by spreader to older trees (4+ years). Solubor® was applied as a foliar spray by air-blast mister, 4 times a year, to trees from 2 years onwards. Paclobutrazol was applied as a collar-drench using a quad-bike mounted sprayer from year 3 onwards. Fertigation methods were not used in this case study.

Annual nutrient application rates (kg/ha) for young trees (0 to 3 years) were initially low and based on industry standards (DPI, 1999). Once trees began producing commercial crops (> 4 years) the annual application rates were then based on estimates of nutrient removal from harvested fruit & fertiliser efficiency. Industry nutrition guidelines (AMIA, 2017) recommended annual nutrient replacement requirements rates per ten tonnes of fruit removed for the key elements N, K, Ca and B at 21.3, 21.5, 14.4 and 5.0 kg/ha/year. Actual and estimated annual fruit yields from the PST (Table 3) were used to calculate these rates. The annual nutrient replacement rates for trees at maximum canopy size (age 11 years onwards) in the four canopy systems are presented below in Table 4.

Table 4. Annual nutrient replacement (kg/element/ha) for the four planting systems at maximum canopy size (age 11+ years) based on fruit removal & fertiliser efficiency.

Element	Industry guidelines (yield 10 t/ha)	Conventional Low (yield 18.2 t/ha)	Conventional Medium (yield 32.6 t/ha)	Conventional High (yield 58.7 t/ha)	Trellis High (yield 65.9 t/ha)
N	21.3	38.76	69.5	125.0	140.4
K	21.5	39.13	70.2	126.2	141.7
Ca	14.4	26.20	47.0	84.5	94.9
B	5.0	9.10	16.3	29.4	33.0

Pest, disease and weed management

Pest and disease management costs included the cost of chemicals and their application based on the requirements for growing B74 mango trees in the Mareeba/Dimbulah region (See Appendices 1 & 2). Insecticides used in this case study were; Trivor®, Transform™, Success®, Applaud®, ParaMite®, Oil and Vayego®. Fungicides used were; Kocide®, Mancozeb, Octave® and Amistar®. An annual pest and disease management spray program was developed using these chemicals (plus foliar applied boron for nutrition purposes) for both non-bearing trees (age 0 to 3 years) and bearing trees (> 3 years). Non-bearing trees require greatly reduced pest and disease management compared with bearing trees and a simple program of only four chemical sprays/annum (including Trivor®, Success®, Oil, Applaud®, Kocide®) was used (data not presented). The full pest and disease management program for bearing trees (> 3 years) included 13 chemical spray operations/annum and is presented in Table 5. This program comprised 13 foliar spray applications with a tractor rear-mounted axial fan air-blast mister (approx. 2,000 litre capacity).

Foliar spray applications frequently combine compatible chemicals in the same spray mix to reduce mister usage and associated costs (Table 5). Within these 13 spray applications; 11 included fungicides, 9 included insecticides and 4 included nutrients. In order to portion out the annual variable costs of the 13 foliar sprays conducted using the air blast mister these were allocated relatively as follows; 6 fungicide applications, 5 insecticide applications and 2 nutrient applications.

The calculation of annual foliar spray costs was conducted using chemical product costs, application costs (machinery and labour) and an assumption that the optimum spray amount to effectively wet a tree canopy is 0.3 L spray/m^3 canopy volume. Application rates per hectare at various canopy development stages were calculated using estimated row canopy volume per hectare which included the spraying of voids between trees within the row (See Table 9). To reduce model complexity, canopy growth was divided into three stages; early, mid and mature, with the volume figure for that stage used to calculate spray volume. Canopy volume growth trends showed two distinct patterns between the four systems; (1) slower early volume growth as shown in low and medium conventional systems and (2) fast early volume growth as shown by the high density conventional and trellis systems. For the conventional low and medium density trees, early stage 0 to 7 years used year 7 volume data, mid stage 8 to 10 years used year 9 volume data, and mature stage 11 years onwards used year 11 data. For the conventional high density and trellis trees, early stage 0 to 6 years used year 3 volume data, mid stage 7 to 9 years used year 8 volume data and mature stage 10 years onwards used year 10 volume data.

Weed management included the cost of herbicides (Roundup), their application (via quad bike-mounted sprayer), slashing costs (tractor-mounted slasher) and associated labour. Weed control operations were highest for the first two years for all four systems due to increased labour necessary for spot spraying. From year three onward, weed management costs dropped due to the ability to quickly band spray under the larger trees.

Table 5. Spray program for 13 insecticide, fungicide and nutrition applications required each season

Spray No.	Fruit Week	Month/s	Phenology	Fungicide	Insecticide	Nutrition
1		Jan/Feb	Flushing	-	Trivor®, Success®	-
2		Feb/Mar	Flushing	Kocide®	Success®	
3		Mar – June	Dormancy	Kocide®	ParaMite® + Oil	-
4		June - July	Dormancy	-	Oil	
5	0	Mid July	Flowering starts	Kocide® + Mancozeb	Transform™ + Success®	Boron
6	2		Flowering	Octave® + Mancozeb	-	Boron
-	4	Mid Aug	Flowering	-	-	-
7	6		Fruit set	Octave® + Mancozeb	-	Boron
8	8	Mid Sept	Fruit set	Kocide® + Mancozeb	Vayego®	-
9	10		Fruit set	Amistar®	Applaud® + Vayego®	Boron
10	12	Mid Oct	Fruit development	Kocide® + Mancozeb	Applaud®	-
11	14		Fruit development	Mancozeb		
12	16	Mid Nov	Fruit development	Amistar®	Trivor®	-
13	18		Fruit development	Amistar®	-	-
	20	Mid Dec	Harvest	-	-	-

Irrigation management

The irrigation rate per hectare for the four canopy management systems was calculated using the industry standard information for a conventional low density mango orchard growing at Mareeba (mean annual rainfall 900 mm). In order to extrapolate these data across the other three canopy systems, canopy surface area (m^2) was selected as the best parameter for comparing relative plant water use for trees at different growth stages over the orchard lifetime (Table 6). A multiplication factor was applied to determine irrigation rate (ML/ha) at four tree ages; 2, 7, 9 and 11 years. The estimated irrigation rates for the four canopy systems are presented below in Table 6.

Table 6. Estimated irrigation rates (ML/ha) at four ages for the four canopy management systems.

Planting system	2 years	7 years	9 years	11 years
Conventional low	1.3	2.6	3.2	4.5
Conventional medium	2.8	5.9	7.2	8.3
Conventional high	4.5	8.5	10.9	11.1
Trellis high	4.3	7.3	9.3	10.0

Results

Establishment costs

The land preparation costs per hectare for the four planting systems investigated were similar and ranged from $1,100/ha for the low density conventional system up to $1,262/ha for the high density systems (Table 7 & Figure 3). The higher costs for irrigation (equipment, materials and installation) and planting for the medium and high density systems were due to the higher number of rows and trees per hectare (Table 7 & Figure 3). For trellised systems, establishment costs also included the costs associated with establishing the trellising infrastructure which included items such as posts, wires and tie-downs (Table 8).

Table 7. 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

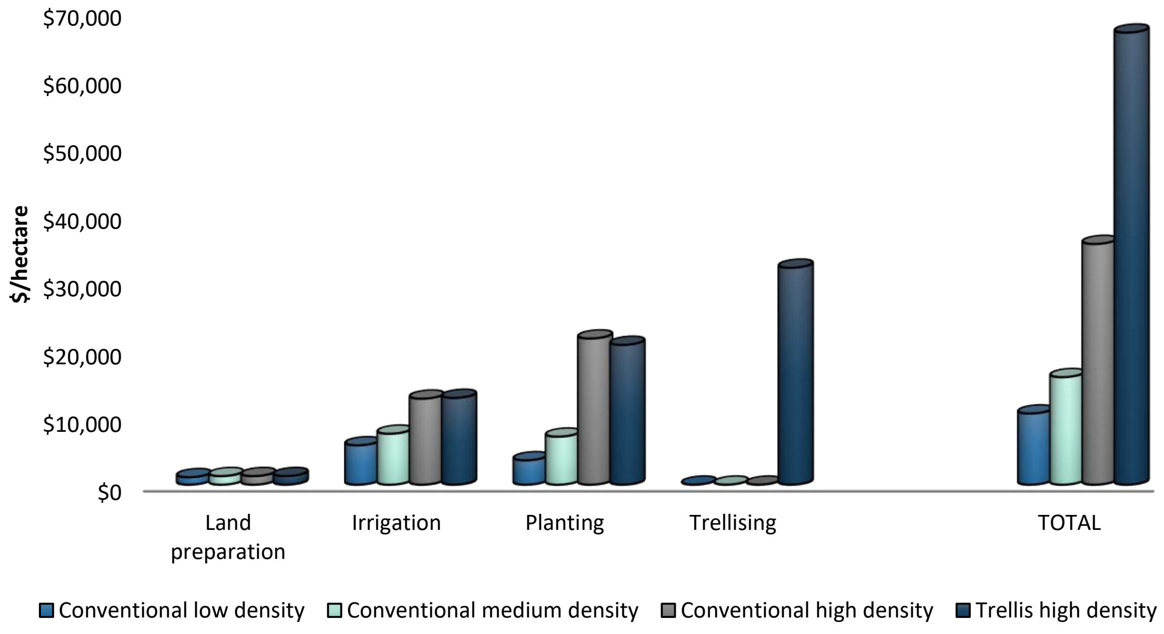

Figure 3. Establishment costs for each planting system: conventional low, medium, and high density and trellis high density in $/hectare.

The configuration and materials selected for the trellis system (Table 8) are the same as the specifications designed to withstand cyclonic winds in north Queensland (Drinnan, *et al.* 2018). The costs to establish the trellis infrastructure alone was estimated at $31,981 per hectare. This is in addition to the typical establishment costs for a conventional farm (Table 7 & Figure 3).

Table 8. Costs of materials and labour for one hectare of trellis infrastructure (current as of January 2020).

Item	Cost ($)	Quantity per row	Quantity/ha (18 rows)	Sub-Total ($)
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	1,296	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)	27.00	6	18	2,916
			TOTAL	31,981

Variable production costs

Nutrition

Nutrition costs for the four orchard management systems are presented in Figure 4. These costs quickly increased for the first four years for all systems due to the annual increase in the fertiliser rate required to support tree growth, and the higher labour costs associated with hand application of fertiliser. For interim years 4 to 11, nutrition costs increased at a slower rate, due to labour savings from use of a fertiliser spreader, and fertiliser rates only slowly increasing over time in response to increasing yields. From peak production, years 11 onwards, fertiliser rates remained consistent for the remainder of the productive life of the orchard. The conventional low density system had the lowest annual nutrition costs at $1,400/ha/year at the time of peak production (Figure 4). The other systems had higher nutrition costs; however this was associated with the higher fruit yields from these systems. The conventional medium density system had a nutrition cost of $2,106/ha/year, the high density conventional system $3,132/ha/year and the high density trellis system $3,016/ha/year at peak production (Figure 4). The nutrition costs for both high density systems were similar for the entire production period due to the similar tree number and yield per hectare (Figure 4).

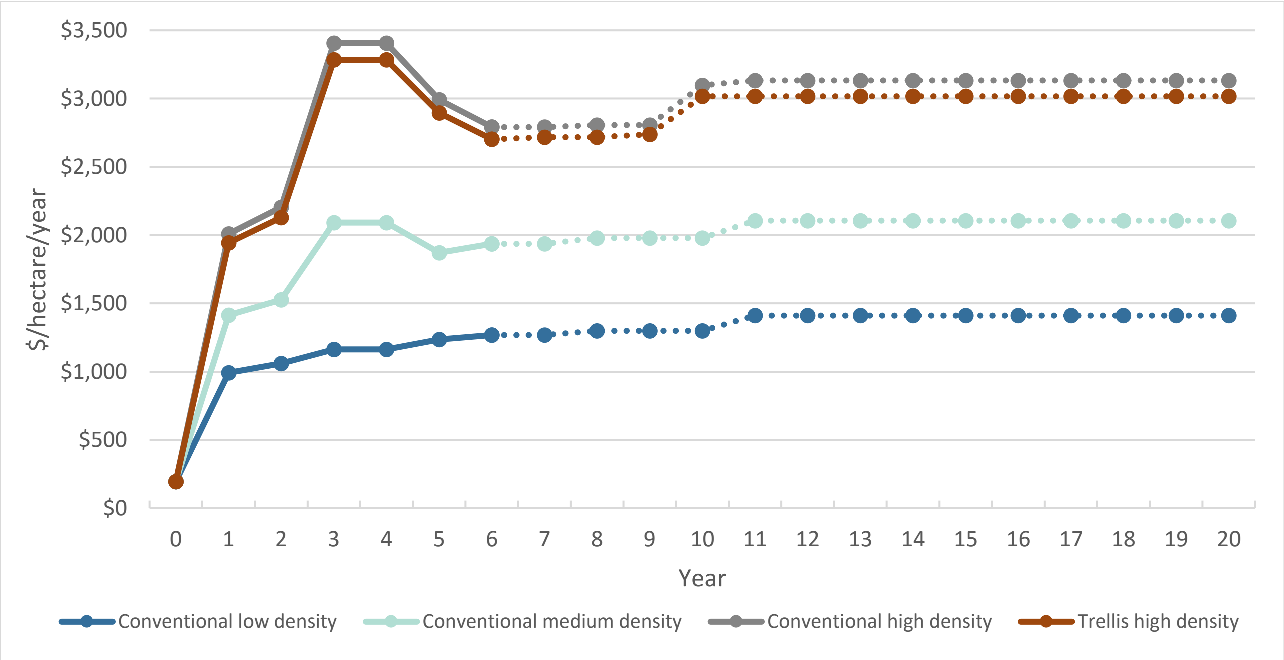

Figure 4. Nutrition costs ($/ha/year). Includes labour, the cost of fertilisers and their application. Data from years 0 – 6 (solid lines) were based on data from the PST. Data from year 7 onwards (dotted lines) were estimated.

Insect management costs

Insect management includes the cost of insecticides and their application. All insecticides were applied as a foliar spray by air-blast mister as per the spray program in Table 5. Foliar application rates (L/ha) were based on canopy volume per hectare and assumed any intra-row canopy voids were also sprayed.

Insect management costs are presented in Figure 5. These costs remained relatively low for the first three years prior to the trees bearing fruit. For the following four years (years 3 to 7), costs increased as the complete spray program was implemented to protect fruit. For conventional low and medium density systems for years 8 to 10, the costs increased in line with increases in canopy volume. These systems were predicted to reach mature canopy volume from year 11 onwards, coinciding with the highest insect management costs for these systems. The trellis and conventional high density systems were predicted to reach mature canopy volume by year 10, hence the maximum insecticide management costs occurred a year earlier than the lower density treatments.

At peak production, insect management costs were $5,415 for the conventional medium density system, the highest of all systems (Figure 5). The conventional low density system was the second most expensive at $3,984/ha/year. At $3,478/ha/year, the conventional high density system was almost $2,000 less than the medium density system (Figure 5). The trellis high density system had the lowest insect management costs at $2,913/ha/year at peak production, which is $2,500/ha/year less than the medium density system (Figure 5).

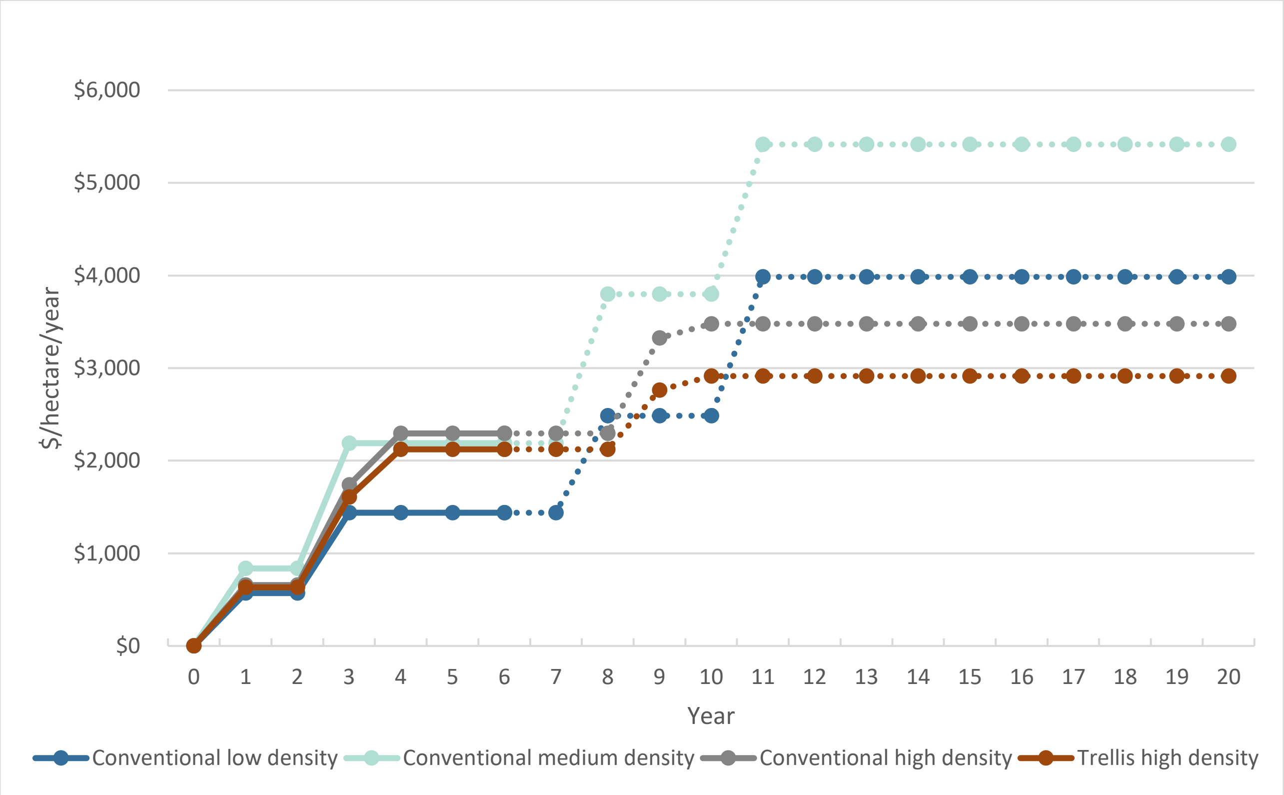

Figure 5. Insect management costs ($/ha/year). Cost of chemicals and their application (including labour) are included in the calculation. Data from years 0-6 (solid lines) were based on data for the PST. Data from year 7 onwards (dotted lines) were estimated.

Disease management costs

Disease management includes the cost of fungicides as well as their application. All fungicides were applied as a foliar spray by air-blast mister as per spray program in Methodology section (Table 5). Application rates (L/ha) were based on canopy volume per hectare and assumed any intra-row canopy voids were also sprayed. Disease management costs are presented in Figure 6. As with insect management costs, disease management costs remained relatively low for the first three years before increasing every three to four years in-line with increases in canopy volume.

At peak production, disease management cost of $6,366 for the conventional medium density system were the highest of all systems (Figure 6). This was due to the medium density system having the highest canopy volumes (Figure 1). The conventional low density system was the second most expensive at $4,560/ha/year. At $3,179/ha/year, the conventional high density system cost half as much as the conventional medium density system (Figure 6). The trellis high density system had the lowest disease management costs at $2,706/ha/year at peak production (Figure 6).

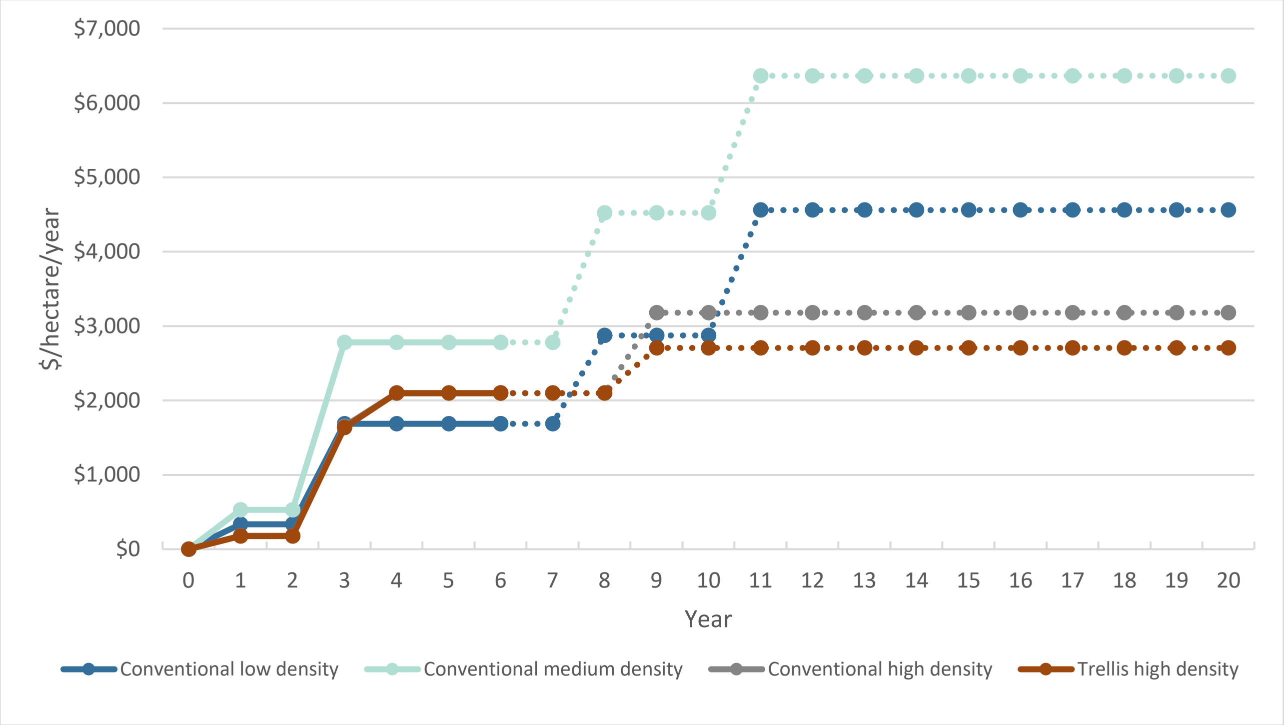

Figure 6. Disease management costs ($/ha/year). Cost of chemicals and their application (including labour) were included in the calculation. Data from years 0 – 6 (solid lines) were based on data from the PST. Data from year 7 onwards (dotted lines) were estimated.

Chemical use efficiency

At maximum canopy size, the conventional and trellis high density systems had the greatest chemical application efficiency as theoretically there were little to no voids between tree canopies within the row (Table 9). In these circumstances the chemical is only applied to the tree canopy and not to open space between trees. Additionally, it is expected that improved spray penetration would be achieved within the trellis system as the mature canopy width (0.5-1.1 m) is significantly less than the conventional low density (3.2-3.8 m). The conventional low and medium densities had a chemical wastage of 37% and 16% respectively, due to the voids between tree canopies. In chemical costs alone, this equated to a loss of $3,161/ha/year and $1,885/ha/year, respectively (Table 9).

Table 9. Chemical use efficiency including costs of chemicals lost in mature systems with voids between trees within the row. (Note. Row canopy volume/ha includes intra-row voids whereas actual tree canopy area/ha excludes intra-row canopy voids).

Planting system	Row canopy volume/ha (m^3)	Tree canopy volume/ha (m^3)	Difference (m^3)	Loss (%)	Crop protection costs ($/ha)	Amount of costs lost ($/ha)
Convention Low	13,215	8,369	4,846	37	8,544	3,161
Conventional Medium	17,620	14,760	2,860	16	11,781	1,885
Conventional High	10,967	10,967	0	0	6,657	0
Trellis High	8,910	8,910	0	0	5,619	0

Weed management costs

Weed management costs are presented in Figure 7. Costs were highest for the conventional and trellis high density systems (exactly the same) throughout the life of the orchard. These systems have more rows than the conventional low and medium density systems, hence side-throw slashing and boom spraying costs would be higher for these systems.

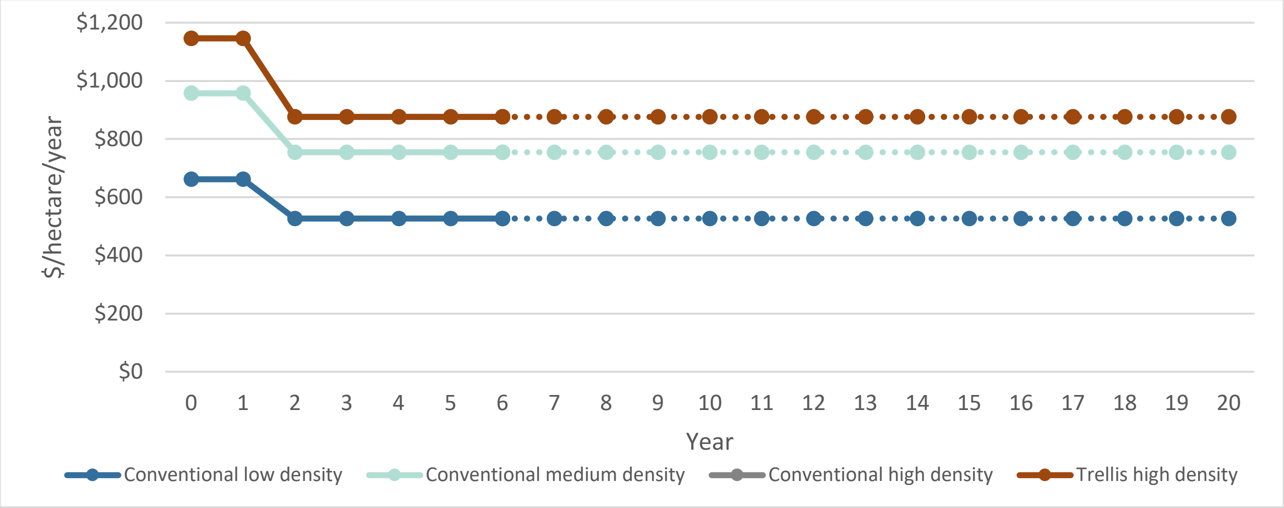

Figure 7. Weed management costs ($/ha/year). Cost of chemicals, their application (including labour) and slashing costs are included in the calculation. Data from years 0-6 (solid lines) were based on data from the PST. Data from year 7 onwards (dotted lines) were estimated. Costs for conventional high density are the same as trellis high density, hence only trellis high density costs are visible.

Irrigation costs

Irrigation costs cover the cost per megalitre of water used as well as the electricity costs for the pump. Application rates (L/ha) were based on canopy surface area per hectare. Sprinklers were used and assumed to irrigate at a rate of 60 L/hour. Irrigation costs for the four planting systems are presented in Figure 8. As with insect and disease management costs, irrigation costs increased every three to four years to coincide with increases in canopy volume. At full production, the conventional high density had the highest irrigation costs at $1,576/ha/year, which was $173/ha/year more than the trellis high density system (Figure 8). This was due to the greater canopy surface area and the extra trees per hectare of the conventional high-density system, compared to the trellis system. The conventional medium density system had the second-lowest costs at $1,160/ha/year. The conventional low density costs were less than half that of the conventional high density irrigation costs ($634/ha/year), again mainly due to the lower canopy surface area for that system (Figure 8).

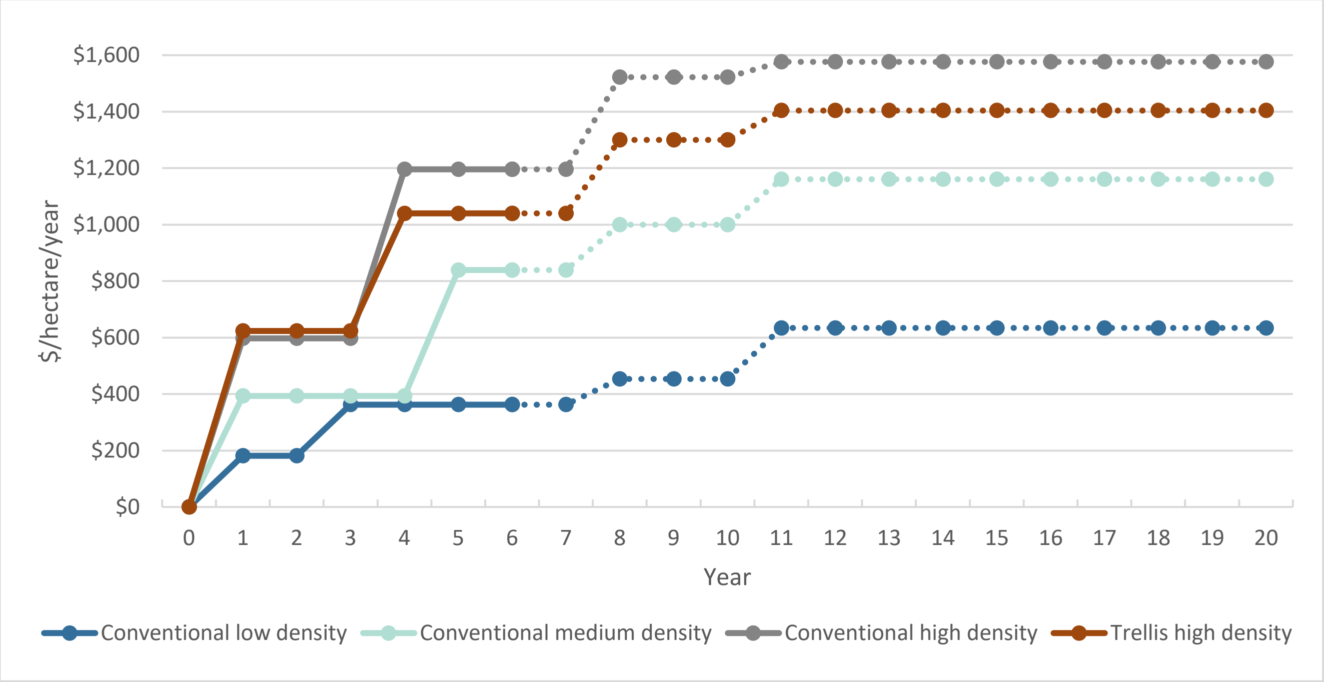

Figure 8. Irrigation costs which include the cost of water usage (per ML) and pump electricity charges. Data from years 0 – 6 (solid lines) were based on data from the PST. Data from year 7 onwards (dotted lines) were estimated.

Pruning, training, bending costs

Pruning costs include hand pruning, mechanical hedging and the various tasks required to establish the correct architecture for the trellis system: pruning, bending, training and tying limbs to trellis wires. Mechanical hedging was assumed to commence from year 5 for the high density conventional and year 6 for all other systems. As expected, in the initial years when tree architecture was established, the trellis system had the highest costs, reaching a maximum of $15,968/ha/year in year 6, compared to $1,617/ha/year for the conventional low density (Figure 9). Pruning costs for the three other systems increased more gradually in line with tree size and canopy complexity. By year 7, the high density trellis and conventional systems had reached mature size. By year 7 the tree architecture was established and less tree training would be required, consequently, costs declined over the following few years before plateauing from year 10 onwards (Figure 9). The conventional high density system had slightly higher costs than the trellis system in the later years $7,706/ha/year and $6,346/ha/year, respectively (Figure 9). This was partly due to the higher number of trees/ha and partly because some hand pruning would still be required for the high density conventional system, on top of the annual mechanical hedging. The conventional low and medium systems pruning costs increased slowly and remained relatively low throughout the orchard lifecycle, reflecting the steady increase in tree size and canopy volume (Figure 9).

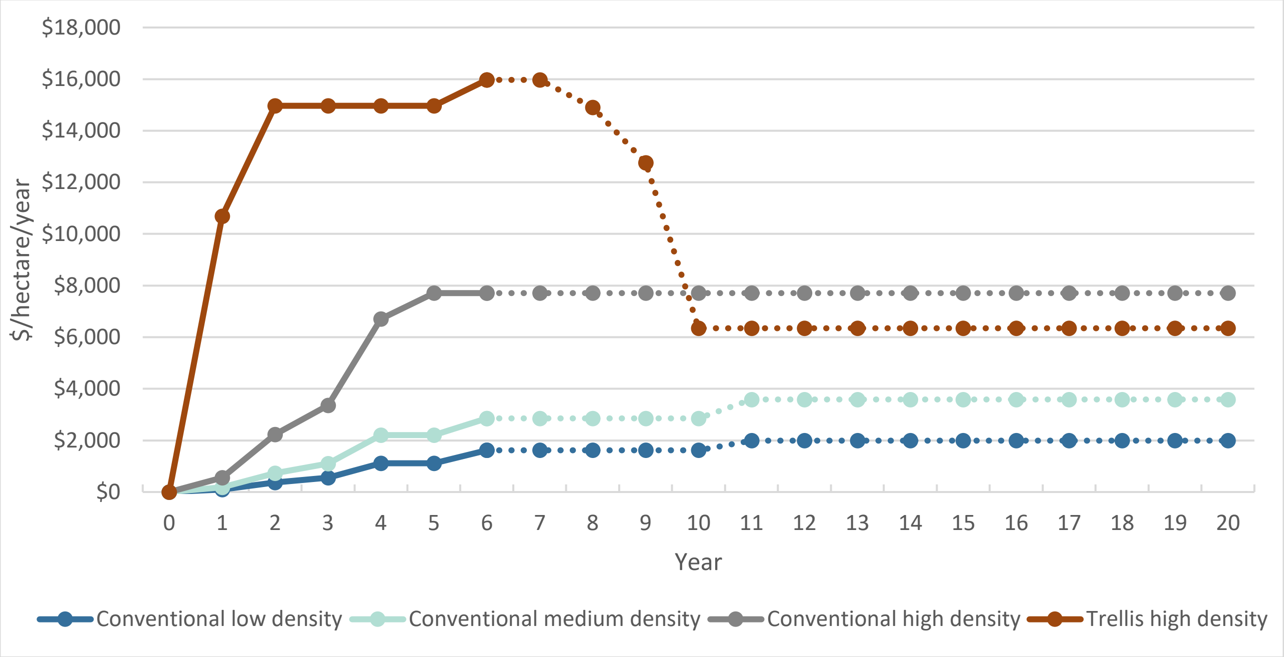

Figure 9. Pruning, training, bending and hedging costs ($/ha/year). Data from years 0 – 6 (solid lines) were based on data from the PST. Data from year 7 onwards (dotted lines) were estimated.

Picking costs

Picking costs include picking labour, harvest aid running costs, forklift and water truck and Mango Wash® and are directly related to the quantity of saleable fruit produced (Figure 10). It was assumed that fruit were picked at a rate of 210 kg/hour/person which equated to a cost of $0.13/kg, assuming a labour cost of $27.00/hr. As expected, due to the higher quantity of fruit produced per hectare, the trellis system had the highest picking cost at full production at $9,485/ha/year whereas the conventional low density had the lowest picking costs at $2,933/ha/year (Figure 10).

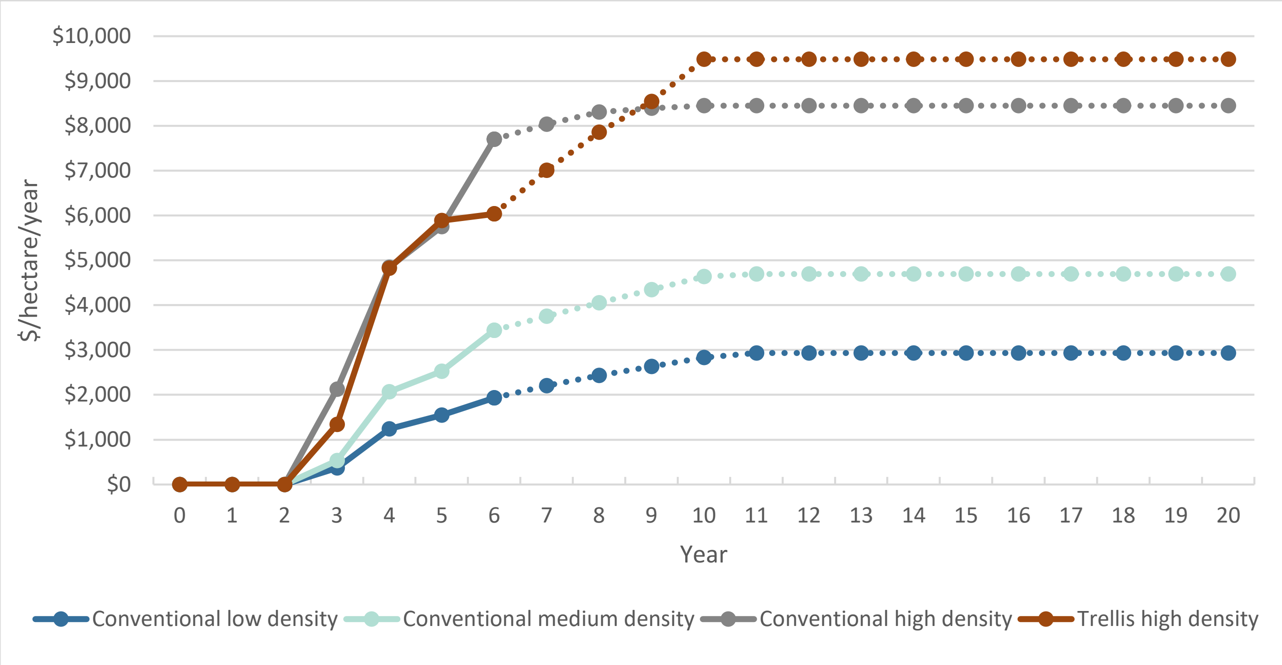

Figure 10. Picking costs ($/ha/year) - includes picking labour, harvest aid costs and Mango Wash® Data from years 0-6 (solid lines) were based on yields recorded for the PST. Data from year 7 onwards (dotted lines) were estimated.

Packing costs

Packing costs were directly related to the quantity of saleable fruit produced and included contract packing costs and freight to the external packhouse (Figure 11). It was assumed that 100% of the saleable fruit was sent to an external packhouse at a cost of $0.02/kg. Included in the contract packing rate of $4.50 per 7kg carton were: fungicide treatment, grading, cartons, inserts, packing labour, quality assurance and palletising. As expected, due to the higher quantity of fruit produced per hectare, the trellis system had the highest packing cost at full production at $41,527/ha/year whereas the conventional low density system had the lowest packing costs at $11,470/ha/year (Figure 11).

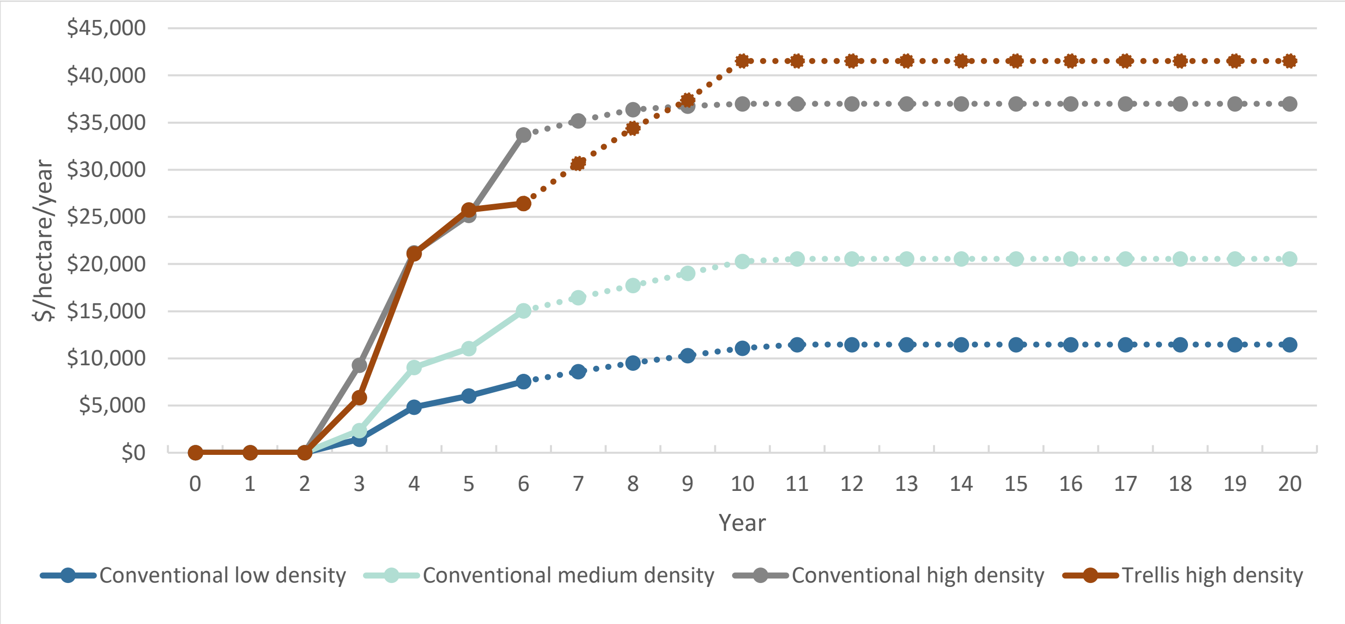

Figure 11. Packing costs ($/ha/year) - includes contract packing costs. Included in the contract packing rate were: fungicide treatment, grading, cartons, inserts, packing labour and palletising. Data from years 0-6 (solid lines) were based on yields recorded for the PST. Data from year 7 onwards (dotted lines) were estimated.

Total Variable Costs

Mid-way through orchard establishment (5th year) the main pre-harvest costs for the conventional low and medium density systems were nutrition, canopy management and pest & disease management (Figure 12). The main difference between the two high density treatments were canopy management costs, due to the higher labour required to prune and train branches in the establishment years of the trellis system (Figure 12). The canopy management costs for the trellis system at $14,968/ha/year were more than double the costs for the conventional high density system at $6,706/ha/year (Figure 12). Weed control was similar across all four treatments whereas irrigation was higher for the higher density systems (Figure 12).

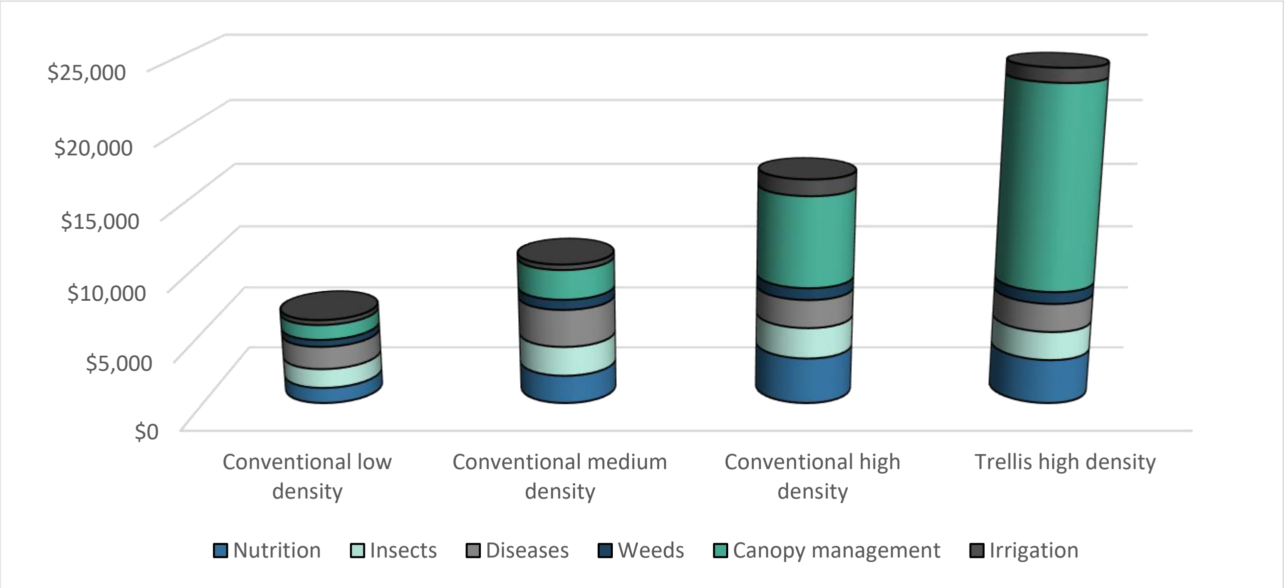

Figure 12. Composition of pre-harvest variable costs at year 5.

Post-harvest variable costs were highest for both of the high density systems (Figure 13). These costs were directly related to productivity, so the more productive systems incurred the highest costs for picking, packing, freight and marketing & levies (Figure 13).

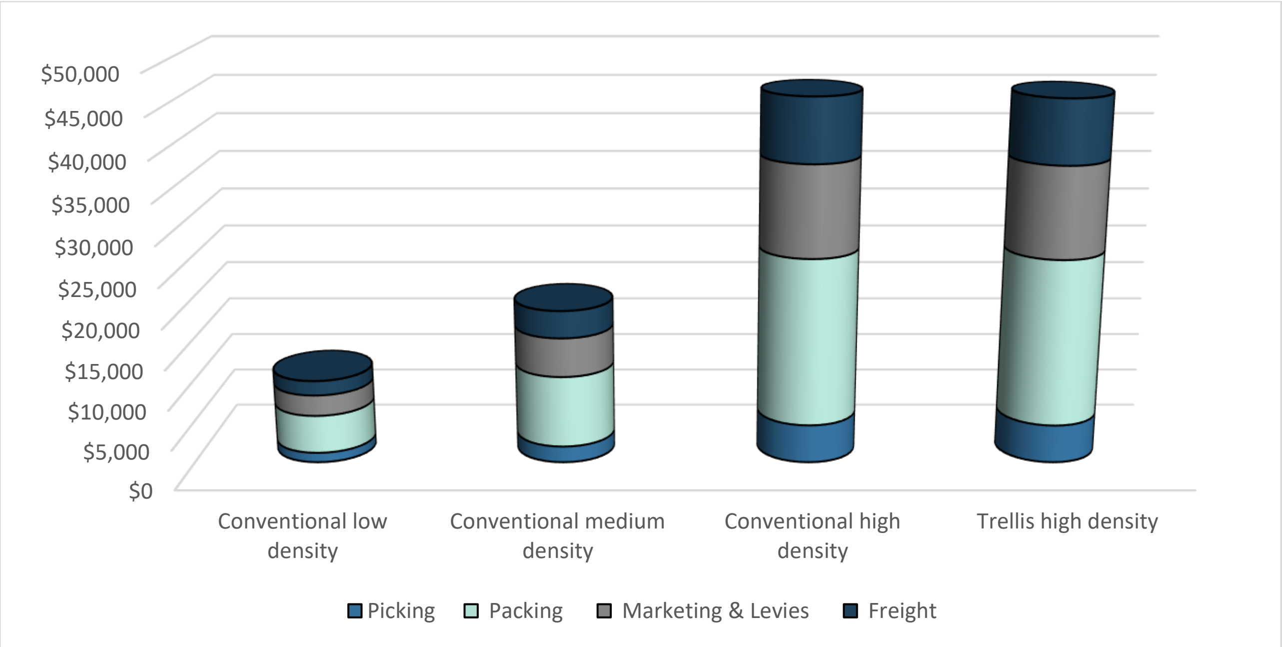

Figure 13. Composition of post-harvest variable costs at year 5.

At full production – from year 12 onwards for all systems – the canopy management for the trellis system reduced to a level similar to the conventional high density system as, by this stage, the tree architecture was established (Figure 14). Pest and disease management were the dominant costs for the low and medium systems whereas canopy management was the dominant cost for the higher density systems (Figure 14). This was a direct consequence of the larger canopy volumes of the low and medium planting systems.

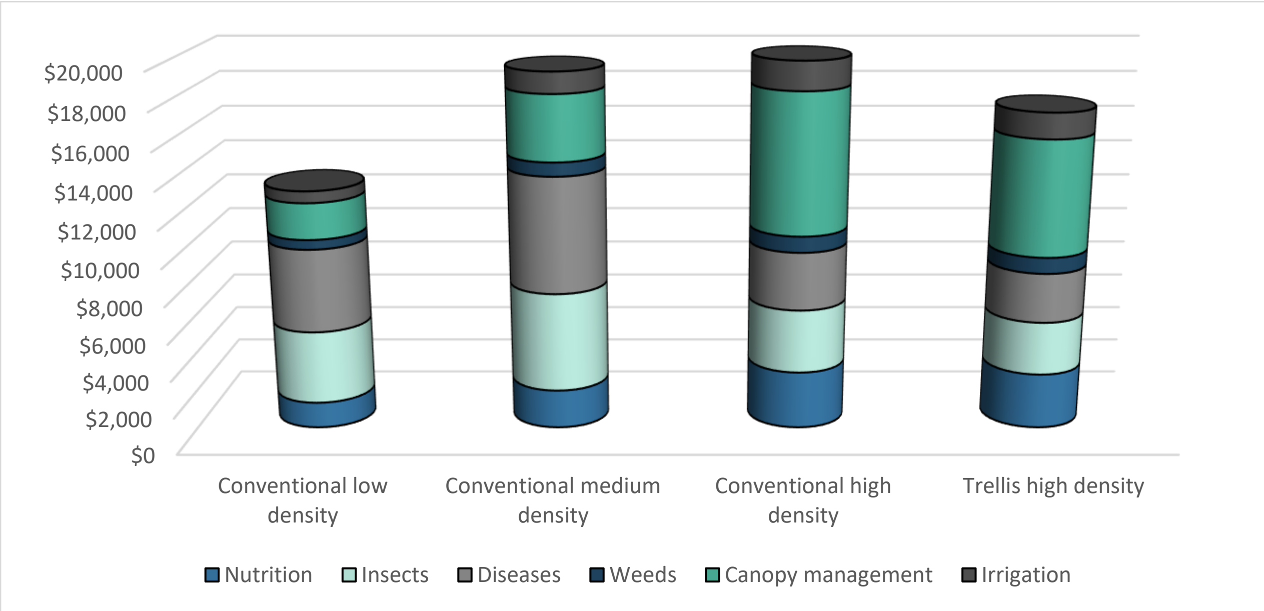

Figure 14. Composition of pre-harvest variable costs at year 12

At maturity, the post-harvest costs were highest for the conventional and trellis high density systems due to their higher productivity (Figure 15).

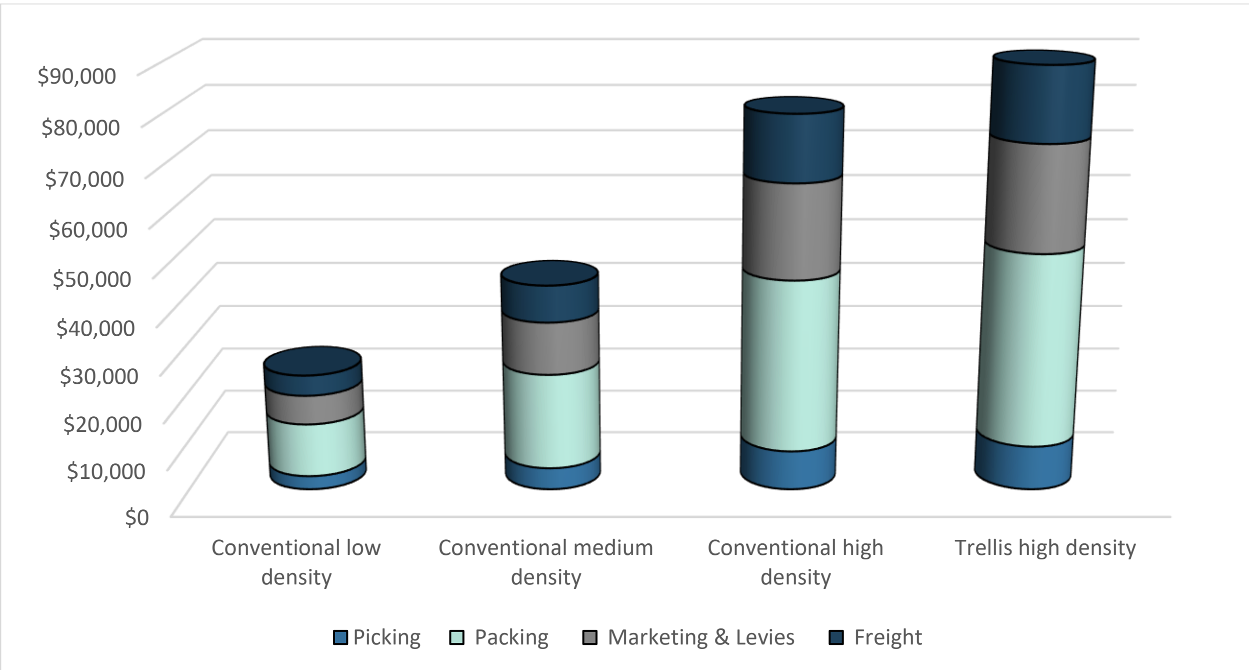

Figure 15. Composition of post-harvest variable costs at year 12.

Income

Yield and Saleable Fruit

Saleable fruit is calculated by multiplying the yield per tree by the tree planting density (Table 3). All planting systems began yielding fruit in the third year after planting (Figure 16). The conventional low density planting was estimated to achieve full production of 17.3 t/ha/year in year 11. The conventional medium density system would also reach peak production of 31 t/ha/year in year 11, almost double the yield per hectare of the conventional low density system (Figure 16). Both the conventional and trellis high density systems were predicted to reach full production one year earlier than the low and medium density systems and at more than three times the yield of the low density system: 55.8 and 62.6 t/ha/year, respectively (Figure 16).

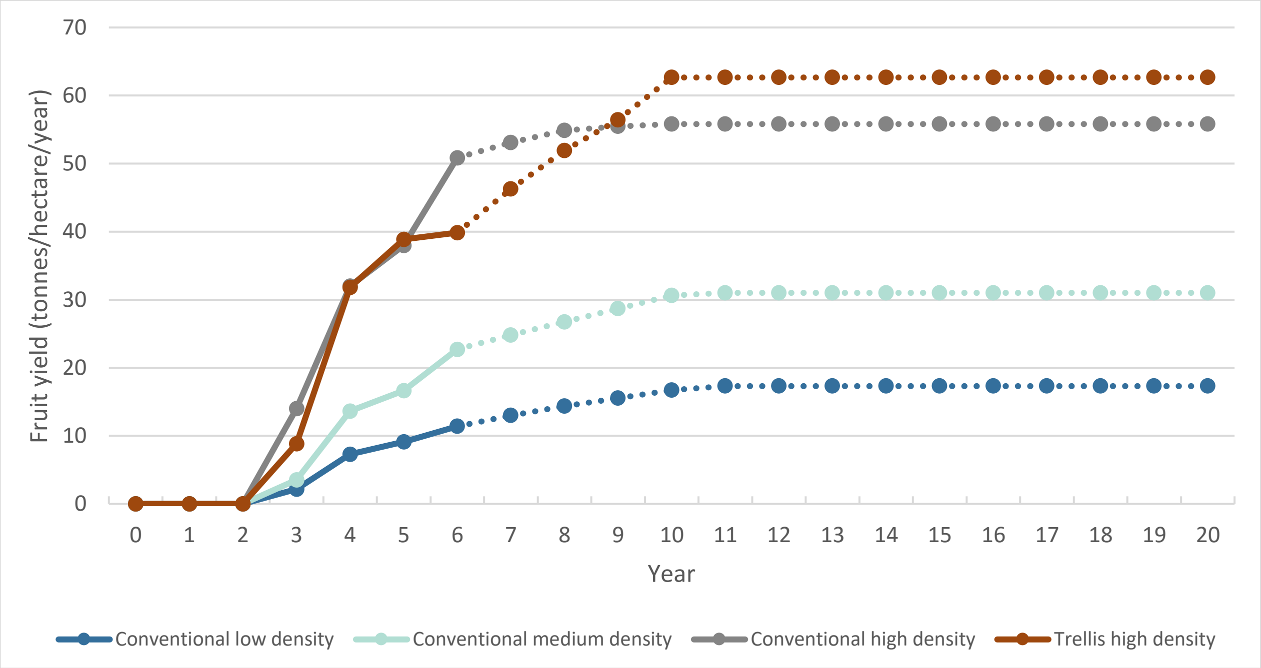

Figure 16. Estimated saleable fruit (tonnes/hectare/year) assuming recovery rate of 95% of biological yield i.e. 5% of fruit is left in the field as waste. Data from years 0 - 6 (solid lines) were based on yields recorded for the PST. Data from year 7 onwards (dotted lines) were estimated.

Gross Revenue

The gross revenue is calculated by multiplying the saleable fruit (Figure 16, above) by the farm gate price. The farm gate price is calculated as the market price minus freight (both to external packhouse and to Sydney market), commissions and levies. Estimated gross revenue is directly related to fruit yield, hence the trends follow those of saleable fruit (Figure 17). The conventional medium density achieved a maximum gross revenue 1.8 times that of the conventional low density (Figure 17). The conventional and trellis high density achieved over three times the gross revenue of the conventional low-density system (Figure 17). At peak gross revenue of $175,800/ha, the trellis system had the highest gross revenue of all systems (Figure 17). The trellis system delivered an additional $19,200/ha in gross revenue/ha above the conventional high-density system of $156,600/ha despite the lower tree number per hectare. `

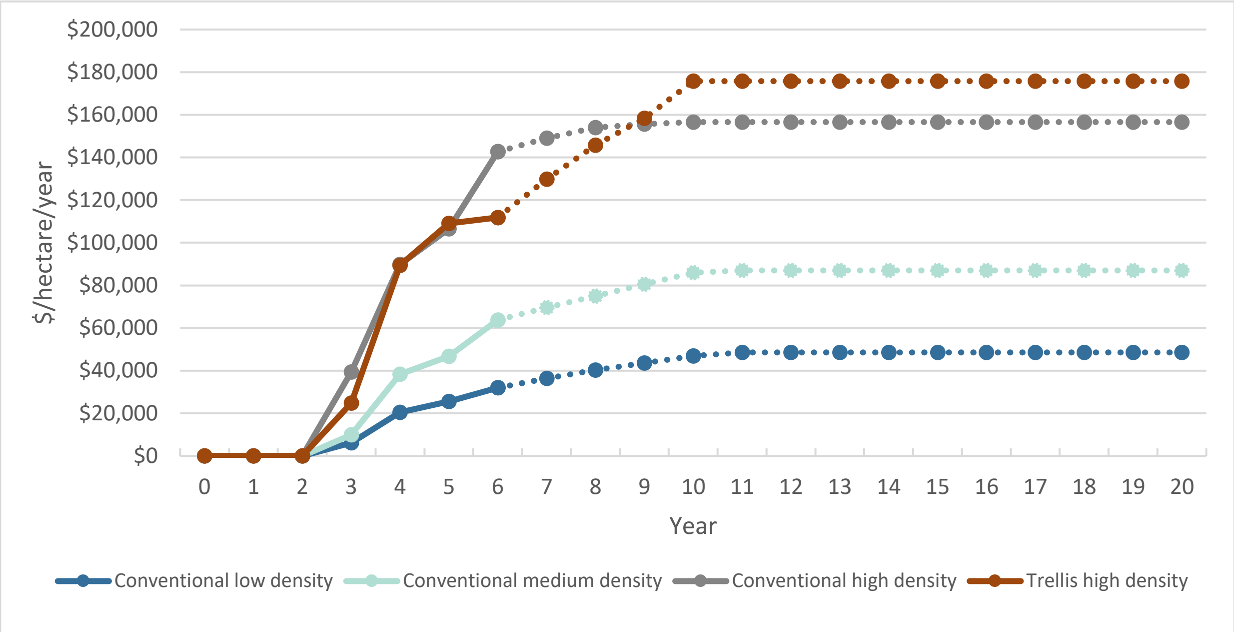

Figure 17. Gross revenue over mango tree life cycle ($/ha/year) calculated as market price minus the cost of freight, commissions and levies. Data from years 0 – 6 (solid lines) were based on yields recorded for the PST. Data from year 7 onwards (dotted lines) were estimated.

Profitability comparison

Gross Margin

The gross margin per hectare was calculated by subtracting the annual costs from the gross revenue for each year after the initial tree establishment. Year 0 represents the establishment costs only up to the stage of tree planting. The initial investment is lowest for the conventional low and medium systems whereas the higher density systems have higher initial costs (Figure 18). This is mainly attributed to the greater number of trees required for both systems as well as the extra investment required for the trellising infrastructure for the trellis system. For years 3 to 9, the conventional high density system produced the highest annual gross margin followed by the trellis system. From year 10 onwards the trellis system had the highest annual gross margin of $108,514/ha/year, over $16,000 more per year than the conventional high density at $92,068/ha/year (Figure 18). The conventional medium density had a gross margin less than half that of the trellis system at $42,867/ha/year while the conventional low density had the lowest gross margin at $21,138/ha/year (Figure 18).

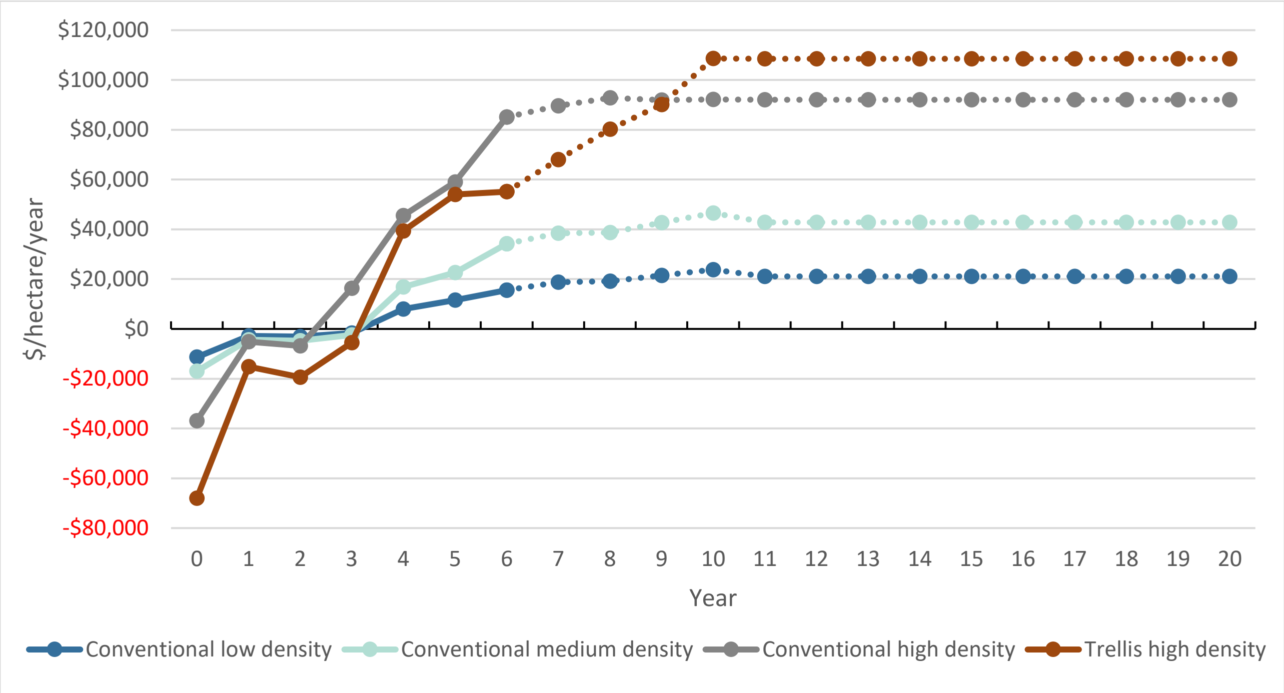

Figure 18. Establishment costs and annual gross margin which is the difference between gross revenue and variable costs each year – not discounted ($/ha/year). Data from years 0-6 (solid lines) were based on yields recorded for the PST. Data from year 7 onwards (dotted lines) were estimated.

Cumulative Nett Cash Flow

The cumulative nett cash flow was calculated by adding the gross margin from the previous year to the following year. The conventional high density system reached a positive cumulative nett cash flow, in year 4, the earliest of all four systems (Figure 19). The conventional low and medium systems took one additional year (year 5, Figure 19). The trellis high density system recorded the first positive nett cash flow in year 6 (Figure 19). By year 11, when maximum canopy size was reached for all systems, the conventional high density system at $617,739/ha/year had a cumulative nett cash flow more than five times the low density and more than double the medium density ($120,484 and 254,473/ha/year, respectively), and reached over $121,000/ha cumulative nett cash flow above the trellis high density that same year (Figure 19).

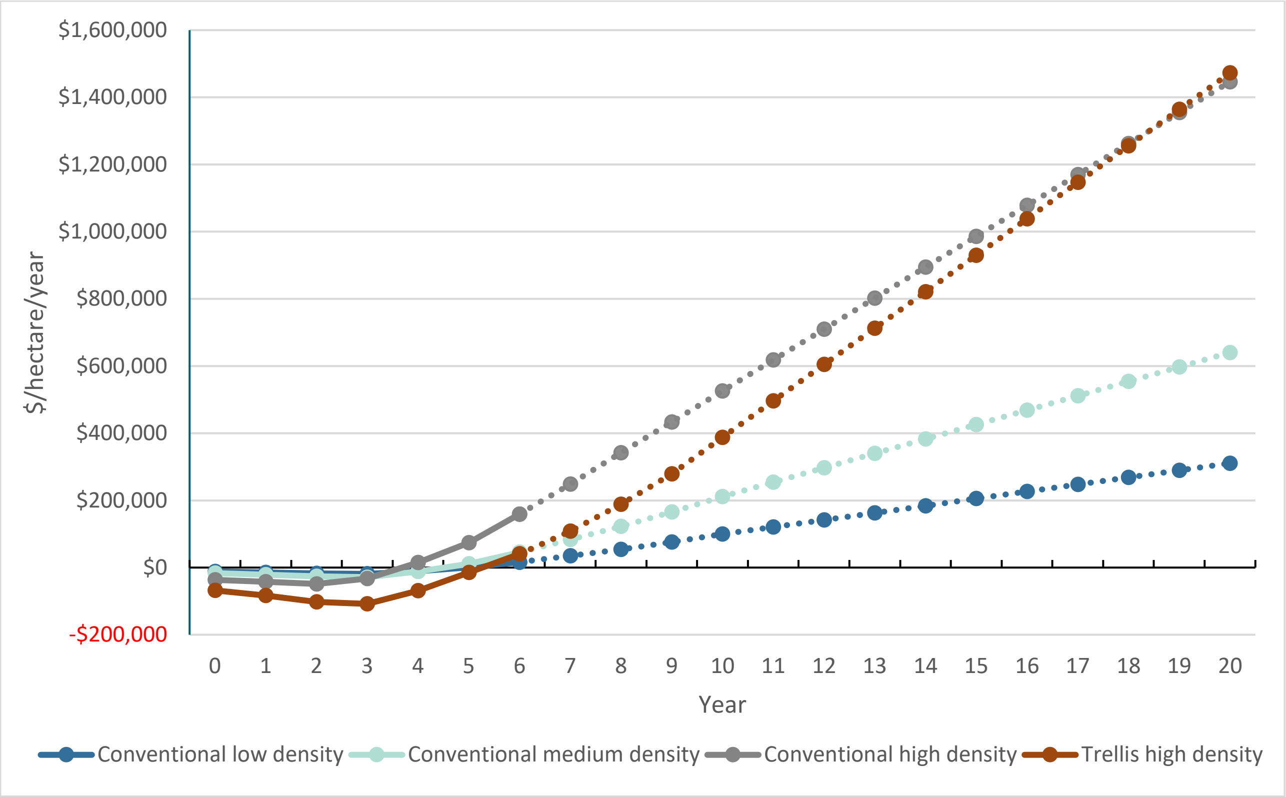

Figure 19. Cumulative nett cash flow, not discounted.

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Appendix 1

A comprehensive table with all products and rates used in this report.

Product	Unit	Unit Cost ($)
Fertiliser		
Lime	Tonne	196.00
Solubor®	Kg	2.96
Nitrophoska special	Kg	1.31
Ozcal	Kg	0.71
Organibor	Kg	1.09
Potassium sulphate	Kg	1.69
Cultar	L	20.24
Insecticide		
Success® Neo	L	450.25
Trivor®	L	198.00
ParaMite®	L	266.13
Transform™	L	291.72
Mineral oil (Biopest)	L	4.71
Applaud®	L	72.39
Vayego®	L	770.00
Fungicide		
Kocide®	Kg	19.84
Dithane (Mancozeb)	Kg	11.45
Octave®	Kg	229.35
Amistar® 250 SC	L	32.87
Other		
Freight cost to external packhouse	Kg	0.02
Freight costs to Sydney market[1]	7kg carton	1.85
Research and industry levy	Kg	0.019
Water	ML	46.00
Electricity	kW hr	0.24
Labour costs	Hr	25.00
Fruit packing[2]	7kg carton	4.50
% of fruit sent to external packhouse	100 %	
Commission/levies	10 %	

Notes: [1]100% of Premium, Class 1 & 2 fruit sent to Sydney market, [2]Included in cost: fungicide treatment, grading, cartons, inserts, packing labour, palletising

Appendix 2

Pests, diseases and nutrition chemicals and application timing

	Spray target	Chemicals	Number of times to control/year	
Insects	Fruit spotting bug	Bulldock or Trivor®^ or Transform™^	4	Flush Fruit set Fruit development x 2
	Mango scale	Admiral, Applaud®* or Trivor®^	6	Flush x 2 Dormancy Fruit set Fruit development x 2
	Flatid, tip borer, shoot caterpillar, shoot borer	Bulldock, Applaud®*	4	Flush Fruit set Fruit development x 2
	Mango seed weevil	Vayego®	2	Fruit set x 2
	Mites	ParaMite®	1	Prior to flowering
Diseases	Anthracnose	Octave®, Mancozeb, Amistar® or Kocide®	9	Flower x 2 Fruit set x 2 Fruit development x 5
	Stem end rot	Amistar®	3	Fruit set x 2 Fruit development x 1
	Bacterial black spot	Kocide®	2	Fruit development
Nutrition	Boron	Solubor®	4	Foliar To complement 1 granular boron applied to soil in Feb

Note:

*Applaud® only registered for mango scale but very effective on leafhoppers, mealybugs, caterpillars.

^Trivor® is less expensive and grower preferred but Transform™ is better on bees/beneficials, especially near flowering.