Department of Primary Industries
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W. Murcott canopy management guide

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Introduction

A project funded by Hort Innovation and conducted by NSW DPIRD explored canopy management practices to alleviate declining mature tree yields and alternate bearing in W. Murcott mandarins. The project spanned over five years, encompassing four seasons of harvest. Replicated trials, grower case studies, demonstration trials and study tours were completed. This guide summarises the practical findings of the project and options for managing W. Murcott canopy. Videos of grower case studies and study tour farm visits supporting this information are available on the NSW DPIRD citrus website.

Key points

Managing watershoots: W. Murcott produce watershoots up to 3 m that bear fruit at the tip, shade the lower parts of the canopy and extend into the middle of the row, restricting tractor access. Managing these watershoots is essential for orchard viability. For vigorous trees, there are 2 main strategies: 1) regular mechanical hedging to reset the canopy with minimal hand pruning, and 2) intensive manual pruning with regrowth management. For medium vigour trees, mechanical hedging provided adequate canopy control and they only required occasional hand pruning.

Strategies depend on tree vigour: trees grafted onto citrange rootstock had high vigour and trees grafted onto Trifoliata rootstock had medium vigour. Installing protective netting over trees (e.g. hail netting 15% shade) increased tree vigour. High vigour trees are more difficult and expensive to manage than medium vigour trees. Using a mix of rootstocks helps with whole-farm canopy management and can improve the spread of harvest.

High vigour tree canopy management: current information suggests there are 2 management strategies for high vigour trees:

1. Mechanical hedging with minimal manual pruning to create a doorway into the tree and remove one inner limb (mostly the central limb). Mechanical hedging does not have a high labour input but does require a hedging machine to be purchased. Mechanical hedging can be contracted, but it is often difficult to book one at the desired time.
2. Intensive pruning requires a significant labour input, mostly in early autumn and some work in spring straight after harvest. It also requires greater commitment in management because delaying pruning can allow trees to grow excessively, which negatively affects future management and cropping. Intensive pruning strategies include trellis and non-trellis systems. Intensive pruning can produce higher yields and less alternate bearing than mechanical hedging.

Mechanical hedging: there are many strategies to hedge a tree, but the most favoured is to heavily cut one side of the tree one season (e.g. about 1 m from the trunk), and then the top and other side of the tree in the following seasons when the canopy restricts access. This removes about one-third of the canopy and creates good tractor access. This strategy is favoured because the non-pruned parts of the tree can bear enough fruit to attract harvest labour, and only removing one-third minimises the shock to the tree. Severely hedging one side of the tree will reduce total yield by about one-third. The cut side bears sufficient fruit in the second or third season and then the other side can be cut. Cutting the top of the tree is determined more by the height of growth than a scheduled cutting. Some growers cut the tops of their trees annually or twice per year. Some manual pruning can also be done to maintain doorways into the tree and remove one internal limb to encourage more internal branching. This doorway and internal limb pruning takes under one minute per tree. Heavy hedging is best implemented when a high cropping year is predicted. A concept not yet tested on severely hedged trees is to remove watershoot growth from cut limbs in late summer to help reduce the outward growth of the tree.

Intensive non-trellis: the key to intensive pruning is managing regrowth to minimise watershoots and encourage more compact and complex fruiting wood. There are 2 main styles: triangular and vase. Triangular tree pruning creates a triangular tree shape with a bottom layer and a central leader forming the top layer of the tree. This is becoming popular in South Africa. Vase pruning is growing an open limb structure like traditional stone fruit pruning. This is suitable for row spacing 6 m or wider. While both methods are very labour-intensive, requiring up to 6–8 minutes of pruning per tree, they can be more profitable as the trees can maintain higher and more consistent yields than if they were mechanically hedged. However, these methods require commitment: missing a pruning session can allow the trees to get quickly out of control and negatively affect yields for many seasons.

Intensive trellis: this cordon growing system was developed by Dean Morris (citrus grower and consultant). Trees are planted at high density (3.7 m × 1.8 m) and trained along a single wire about 800 mm above ground level. Upright limbs are trained to grow at about 450 mm apart (cordon). These upright limbs form a flat, 2-dimensional canopy structure. The cost of the trellis is significantly less than a full-wire trellis system ($3,000/ha compared to $28,000/ha, respectively). This system requires similar pruning and regrowth management to a triangular or vase pruned tree. Orchards using this system are now 8 years old and have reached 55 t/ha production levels. Establishing the orchard with a trellis system is more expensive than a triangular or vase pruning system because of the trellis and higher tree density, however, the trees can be harvested with a picking platform or, potentially with a robotic harvester. Trees on a trellis might require slightly less annual pruning than the triangular or vase pruning system.

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Background

The W. Murcott is a late season mandarin increasing in popularity worldwide and in Australia because the fruit is robust, seedless and exportable by sea freight (good storage life), giving it strong consumer demand. Growers like the variety because it yields well throughout the early years of production and financial returns have been good. W. Murcott mandarins are also sometimes called Nadorcott or Afourer and there are a few privately owned genetically seedless W. Murcotts. Australia has 3,200 ha of W. Murcott mandarin with about 65% of production in the eastern and southern states (2023 CAL tree census). Production has surpassed Imperial mandarin (1,600 ha, 2023 CAL tree census). Some trees have still not yet reached full production, however, 3,200 ha of W. Murcott at an average yield of 45 t/ha equates to 144,000 t annually. Production has been rising sharply over the past 10 years and prices have been decreasing from about $1,300/t to $800/t.

Once W. Murcott mandarin trees reach 10–14 years of age, they are large and prone to alternate bearing, e.g. the trees yield 100 t/ha one season and then drop to 20 t/ha in the following season. Apart from the marketing problems caused by variable volumes of fruit year by year, high yields are often associated with small fruit, while low yields are associated with very large fruit with coarse rinds and reduced flavour. Long-term yields also decline because of large canopies shading the lower productive canopy and the necessary use of mechanical hedging to manage overgrown canopies. A 20 t/ha decline in average yield (55 t/ha to 35 t/ha) equates to an annual loss of $51 M annually.

A Hort Innovation Australia project funded by citrus levies, federal funds and NSW DPIRD, was conducted over 4 years to investigate canopy management options to minimise alternate bearing and yield decline in W. Murcott mandarins. The project included 5 replicated mature tree trials, 2 young tree trials, 3 demonstration trials and 2 international study tours. Information from the project is available through videos and reports on the NSW DPIRD website (https://www.dpi.nsw.gov.au/agriculture/horticulture/citrus/content/canopy-management).

W. Murcott growth habit and watershoots

W. Murcott on vigorous rootstock grows quickly in the early years and is very productive (Figure 1, left). When the trees reach about 10 years of age, they are at their maximum productive capacity because they have the maximum volume of productive canopy around the tree, yet there should still be enough space between the trees for tractor access (Figure 1, right).

Figure 1. Left: young W. Murcott trees are productive from an early age. Right: when the trees reach about 10 years of age, they have high levels of production.

From year 10, the canopy continues to grow and extends into the middle of the row. There is a narrow space between trees that barely allows a tractor through early in the season, and later in the season, tractors are blocked by canopy as fruit weight lowers limbs that extend into the middle of the row (Figure 2, left). The narrow gap reduces light interception to the lower parts of the canopy and makes it less productive and fruitful. The centre of the tree is devoid of a productive canopy because it is shaded by the vigorous outer canopy. Most fruit is produced at the top of the tree where it is difficult to apply spray and harvest, and it has high levels of wind blemish because it is exposed to the elements.

Mechanical hedging is often used to enable tractor access and reduce tree height to make it easier to harvest fruit at the top of the tree (Figure 2, right), but this eliminates a lot of the productive fruiting wood and reduces yield.

Figure 2. Left: the trees become large with shoots extending into the middle of the row and most fruit is on the tree perimeter. Right: the trees are mechanically hedged, which removes productive fruiting wood and decreases yield. The tops of the trees are hedged every year or second year, removing a significant portion of the canopy that would bear large numbers of fruit.

The vigorous growth habit of W. Murcott mandarins is mainly because of watershoots, which are vigorous upright shoots that can grow up to 3 m in a season (Figure 3, left). Watershoots are often devoid of growth on the lower parts, having most of the leaves and complex minor shoots on the upper third. They can quickly extend the tree canopy and often bear fruit on the tips of the shoot. Watershoot growth has a high level of apical dominance whereby shoot tips produce auxin that suppresses lower bud and new shoot growth. When the shoots produce fruit, sometimes the weight of the fruit bends the limb over where it extends into the middle of the row (Figure 3, middle). This impedes tractor access for foliar sprays and the ability to put harvest bins in the row (Figure 4), making harvest challenging.

Figure 3. Left: a vigorous watershoot with few leaves at the base and most of the fruiting wood at the end of the shoot. Middle: watershoots emerging from the outer part of the canopy, bearing fruit and bending down with the weight of the fruit into the middle of the row. Right: watershoots growing in the centre of the tree can form straight, upright limbs with leaves and branches at the top part of the canopy. These shoots bear fruit that is too high to harvest and are often removed annually, resulting in an unproductive central limb that shades the lower part of the canopy.

Figure 4. When the canopy extends into the middle of the row and bears fruit, the fruit is prone to damage from the tractor and machinery and is susceptible to post-harvest breakdown during shipping.

The watershoot growth habit of W. Murcott mandarins differs greatly from navel oranges and is similar to high vigour mandarins. When medium vigour navel oranges are pruned, they mostly produce complex fruiting shoots and nil or very few watershoots. Annual pruning of navel oranges suffices to promote a productive canopy. Implementing a navel orange pruning philosophy on vigorous W. Murcott mandarins will probably give poor results, sometimes creating a worse situation than before pruning. The key to pruning vigorous W. Murcott trees is to recognise the challenge of managing watershoots and applying an appropriate strategy to either work with the watershoots or transform them into productive canopies. The following sections provide information on the strategies and challenges of various options for managing watershoots.

Canopy management considerations and options

Every farm has different management factors, resources and priorities that include availability of labour, cash flow, machinery, management style and skill, so each farm will require different solutions. This guide presents canopy management options based on specific assumptions, and the reader needs to consider these to decide which canopy management option best suits their specific circumstances.

Tree vigour variability: rootstock and site influence

The vigour of W. Murcott mandarin trees varies throughout the regions of Australia. It is influenced by rootstock, climate and soil type. A medium vigour tree will require fewer canopy management inputs and challenges than a high vigour tree.

Rootstock

Rootstock has a strong influence on tree vigour. The 2 most commonly used rootstocks are Citrange and Trifoliata. Citrange rootstock grows a vigorous tree, while Trifoliata grows a medium vigour tree (Figure 5). Medium-vigour trees are slower growing and smaller than vigorous, fast-growing trees and would have slightly less yield than high-vigour trees (about one year behind in yield). However, they would have equivalent yields once they reach full size. The slower growing trees might have a higher average yield because they require a less aggressive pruning program than high vigour trees.

Rootstocks also influence maturity time and fruit quality. Citrange rootstock produces the earliest maturing fruit and Trifoliata fruit matures about 2 weeks later. Citrange produces slightly larger fruit than Trifoliata (1–2 mm larger), however, Trifoliata has higher °Brix and acidity levels that improve the taste. Macrophylla rootstock produces the largest fruit size, but its °Brix and acidity are lower than citrange and might require deficit irrigation to improve the internal quality. Macrophylla is also susceptible to citrus tristeza virus. There are new Chinese rootstocks of various vigour that could have potential for W. Murcott.

Figure 5. Left: a 12-year-old W. Murcott orchard grown on citrange rootstock. The trees have had mechanical topping and side hedging to maintain height and tractor access. Right: a block of W. Murcott trees grown on Trifoliata. They are 20–30% smaller than the citrange trees and have not yet required hedging. The Trifoliata rootstock trees could be planted at a narrower row spacing than citrange rootstock trees.

Site conditions and management factors

Cooler climate suppresses growth compared to warmer climates. Trees grown in the Riverina on citrange rootstock and sandy soil are vigorous, but are slightly less vigorous than trees grown in Sunraysia.

Trees grown in the Riverina on clay loam soil and Trifoliata rootstock have much less vigour than trees grown on citrange rootstock in Sunraysia on sandy loam soil (Figure 6). These trees only require pruning once every 2 years, while the Sunraysia trees require annual (or more) pruning to maintain tree size.

Figure 6. W. Murcott trees grown on Trifoliata 22 rootstock in the Riverina have medium vigour, requiring minimal pruning after being reworked in 2018. The trees on the left were recently pruned and the trees on the right are ready to harvest. These trees are lightly hedged and have 2 upright branches removed each year.

Irrigation can also influence vigour. Deficit irrigation trials conducted by NSW DPIRD at Dareton on navel oranges showed a reduction in summer shoot numbers and size. Most W. Murcott orchards are maintained at a high-water status, and reducing irrigation frequency to refill point might help reduce tree vigour. While there are no data to prove these observations yet, such trials could be implemented by installing taps in irrigation lines to miss every second or third irrigation.

Excessive nitrogen can stimulate tree vigour. A nitrogen imbalance can occur if nitrogen rates are not decreased when yields decline. Nitrogen application rates need to be adjusted on a block basis by assessing yield, leaf size and colour (deficiency or excess symptoms) and leaf nutrient analysis results. Soil solution monitoring can provide further nutritional information.

Mechanical hedging

Mechanical hedging uses a series of rotating cutting blades attached to a large tractor with a protective screen to make linear cuts to the tree (Figure 7). A mechanical hedger can make light cuts to trim branches extending beyond the tractor line or severe cuts up to 1 m from the tree trunk. The mechanical hedger is also used to cut the top of the tree to reduce tree height (topping).

Figure 7. A mechanical hedging machine indiscriminately removes the canopy but is a quick and inexpensive method to cut large portions of the tree's canopy.

Topping

Topping is done to W. Murcott trees that are too high to manage and harvest. Some growers top trees twice a year to encourage more light and fruiting wood growth inside the tree (Figure 8).

Annual topping is especially important for trees growing under protective netting to prevent the canopy from coming in contact with the net and tearing holes. Maintaining an acceptable tree height is also important to keep fruit within a safe picking height. Some orchards implement maximum harvest height limits and some harvest contractors specify a maximum height for their pickers.

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Figure 8. W. Murcott trees that were topped in early autumn. These trees were topped because they will be covered with a net to exclude bees during flowering to produce seedless fruit. A small amount of soft growth will occur on the top to help bed the net on top of the tree. This reduces the incidence of the net getting caught and ripping when it is removed. Some growers top trees in autumn as a way to improve light into the tree.

Topping also produces a thicket of growth on top of the tree because successive topping operations leave behind a stubble of growth on the end of the limb (Figure 9). This thicket of growth is colloquially known as a ‘witch’s broom’.

Figure 9. A thicket of growth at the top of the limb where it is cut back annually.

Topping reduces the tree’s productive canopy bearing area and subsequent yield. The top of the tree has the greatest amount of light exposure and canopy to grow fruit (Figure 8), but it is removed because of the excessive tree height. This is an unavoidable reality of growing vigorous trees and managing the canopy with mechanical hedging.

Sometimes growers try to top every second year and allow fruit growth on the top of the tree. This is possible for medium vigour trees, but on vigorous tall trees, pickers might not harvest fruit that is out of reach, leaving it to become a fruit fly breeding site.

Mechanical hedging strategies

Half-tree severe hedging

The preferred mechanical hedging strategy is to severely cut (e.g. about 1 m from the trunk) one side of the tree one season (Figure 10) and then the top and other side of the tree in the following season, when appropriate. It removes about one-third of the canopy and creates good tractor access.

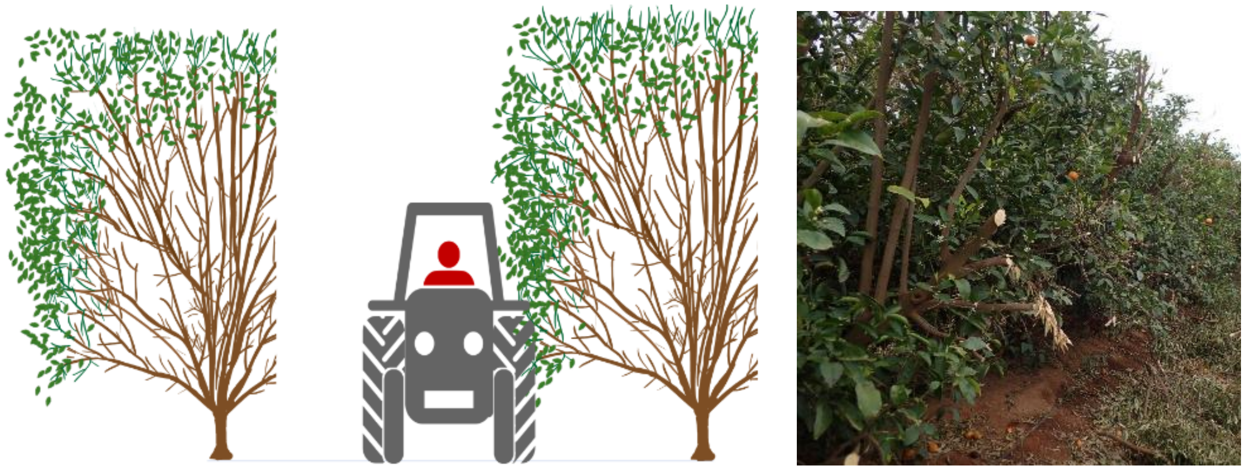

Figure 10. Half-tree hedging removes a major portion of the canopy on one side of the tree. It is one way to rest the canopy, allow tractor access and for new canopy to grow.

This strategy is favoured because the non-pruned parts of the tree can bear enough fruit to attract harvest labour, and only taking one-third minimises the shock to the tree.

The yield on the cut side of the tree decreases by 65–80%. This results in a total tree yield reduction of 30–40%. The fruit yield on the cut side of the tree is mostly from the top of the tree. If the tree was topped when it was side cut, then the yield reduction on the cut side would be 90%. It will take 2 seasons for the cut side to return to being fully bearing (Figure 11). When the cut side bears sufficient fruit, the other side of the tree can be severely hedged. Occasional light hedging is used to maintain tractor access.

Cutting the top of the tree is determined more by tree height than a scheduled cutting program (see topping section).

Some manual pruning can be implemented to maintain doorways into the tree and remove one or 2 internal limbs or watershoots to encourage more internal canopy (Figure 12). This doorway and internal limb pruning takes about 45–60 seconds per tree per annum. Replicated trials could not statistically prove a benefit in yield compared to not conducting the doorway manual pruning, but there was a trend for improved yield in one of the 3 trials. Gaining better tree access has many management benefits, such as easier harvest and better spray penetration.

Figure 11. Left, the canopy growth and mature fruit one season after heavy hedging and right, 2 seasons after heavy hedging.

Figure 12. A small amount of manual pruning can complement a hedging program by cutting a doorway into the tree and annually removing one or 2 upright central limbs or watershoots. This helps with harvest access and encourages some internal canopy growth. Left: a doorway into the tree. Right: the middle of the tree is more open and exposed to sunlight to promote canopy growth.

Severely hedging when a high cropping year is expected will help to reduce the excessive crop load, however, the effect is localised to one side of the tree. It also might exacerbate alternate bearing because the cut side will be at full bearing in the second season, which is when the tree will naturally be in an 'on' or high-yield bearing cycle. Severely hedging in an 'off' or low-yielding year can help minimise alternate bearing, but it will make harvest more challenging because pickers will be reluctant to harvest low-yielding trees unless a premium bin rate is offered (i.e. higher picking cost for that season). However, having one season of difficulty might compensate for future years of reduced alternate bearing.

The new growth on the cut side of the severely hedged tree will be a mix of medium vigour shoots and watershoots. The medium vigour shoots are favourable because they reduce the extension of growth into the row that obstructs tractor access (Figure 13). Unfortunately, watershoots dominate and shade this medium vigour growth and it dies out, leaving behind the watershoot. A concept not yet tested is to remove watershoot growth in late summer to help reduce the outward growth of the tree and keep medium vigour shoots.

Figure 13. The cut side of the tree produces a mix of canopy with favourable medium vigour shoots (left) and unfavourable watershoots (right).

Annual light hedging

Severely hedged trees can have light annual side hedging to remove protruding growth. After many years of mechanical hedging, the sides of the canopy form a flat wall of thin, small, complex shoots (Figure 14).

Figure 14. Repetitive hedging on the side of the tree produces a flat wall of canopy. Eventually this canopy is mainly composed of thin complex shoots with reduced bearing capacity.

Complex short canopy is favoured in most situations where the tree has a dynamic canopy shape with openings on the side of the tree for fruit to bear along the branch and within the tree. However, annually side-hedged trees promote this complex wood on a flat vertical plane and any new growth that can bear fruit is trimmed each year. The continual trimming might also weaken the canopy because there will be too many complex shoots. This type of canopy has an increased risk of alternative bearing because of the synchronisation of canopy growth produced by hedging.

Tree reset or box hedging

Tree reset, or box hedging, is removing 70–90% of the canopy by severely cutting the top and sides of the tree. This is a quick way to reset the tree. It will produce a high vigour response, with many watershoots up to 3 m. When these shoots grow and form into limbs, the tree has a very upright internal limb structure with many limbs and most fruiting wood is at the ends. Time and effort are required to manage the regrowth from a reset tree. The high vigour regrowth response means it will not set fruit in the first season and only have a reduced amount in the second year. Cropping will return in the third year, but the tree will have an elevated risk of alternate bearing because all the new growth is synchronised to bear fruit.

The progression of staggered double-row planting trees that were reset hedged is shown in Figure 15 to Figure 17. Trees were cut to 1.6 m in August 2020. Regrowth was very vigorous in the following season. A thicket of regrowth was in the middle of the tree, which was managed by mechanical topping in subsequent years. This prevented any crop from growing on the top of the tree. In 2024, the new regrowth produced flowers and fruit, but only on the side shoot because of the topping program. The reset topping did not improve yield and every second row of the staggered row was removed to convert the orchard to a wide-spaced single-row planting.

Figure 15. Left: the staggered double-row planting. Right: a mechanical hedging machine resetting the western side of staggered double-row planted trees by topping them at 1.6 m.

Figure 16. Left: the regrowth in July 2021 from topping the tree in August 2020. No fruit set on the tree. Right: some fruit was harvested from the lower portion of the tree in 2023 that was not cut back by the hedging machine.

Figure 17. Left: the side shoots from the new regrowth and the uncut lower part of the tree produced fruit. Right: the inner part of the tree was an impenetrable thicket of limbs. The trees were topped to maintain tree height, so there was no fruit on the top of the tree. If there was fruit inside the tree, it would be difficult to access for harvest.

Economics of mechanical hedging

The cumulative cash flow of W. Murcott mandarin production scenarios grown without protective netting is provided in Figure 18. Cumulative cash flow is like a bank account balance. At the beginning of the enterprise (year 0), money needs to be borrowed to prepare the soil, install irrigation and plant trees; there will be a negative bank balance and 7% interest is paid on the borrowings. Eventually, income is generated by harvesting fruit and the borrowings are repaid. When all the borrowings are paid, the bank balance is zero (breakeven). Any further income increases the bank balance (cumulative cash flow) in subsequent years.

The scenario assumptions are: 667 tree/ha planting density, a fruit price of $800/t, trees are pruned by mechanical hedging (no hand prune), and a cost of $120/bin to harvest trees. The mechanically hedged trees include 1-minute doorway and inner limb hand pruning (+1 min prune). A more detailed economic analysis of mandarins will be presented in a separate report (published by December 2025).

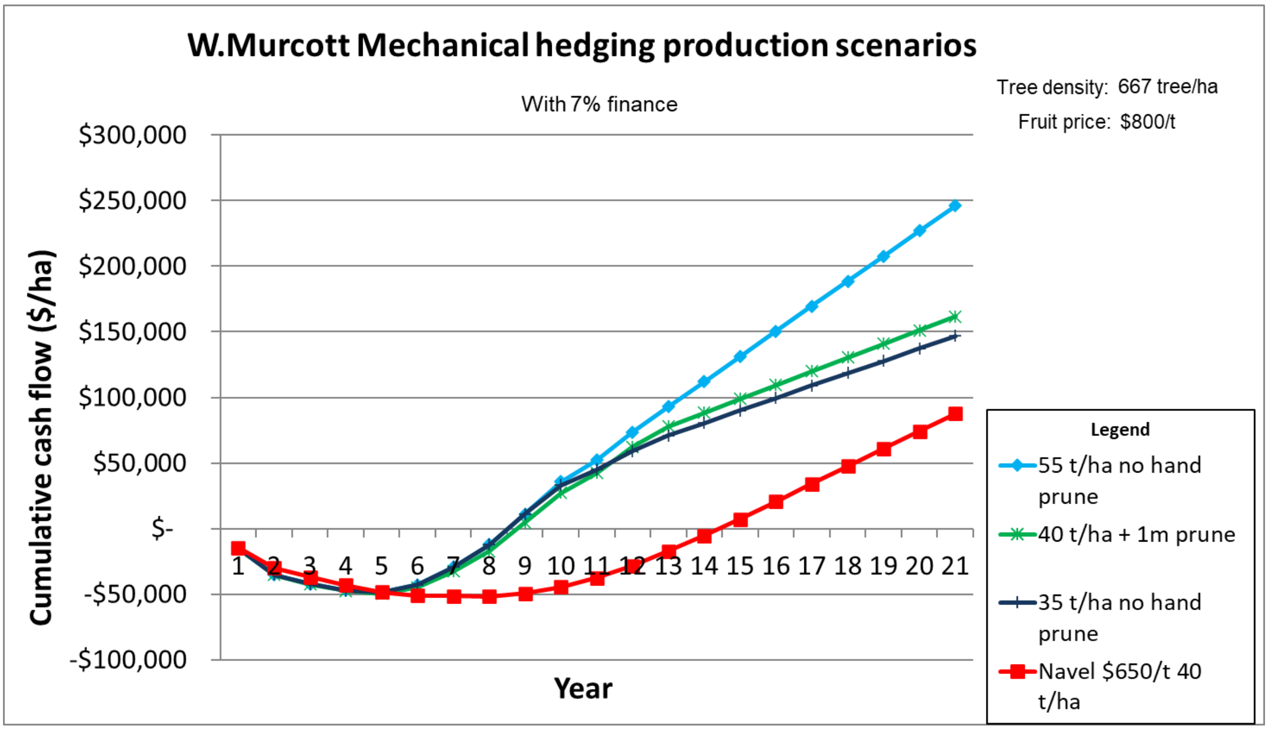

Figure 18. Cumulative cash flow of W. Murcott mechanical hedging production scenarios.

The light blue line '55 t/ha no hand prune' scenario depicts the ideal situation where W. Murcott continues to be productive throughout the 20-year production cycle, assuming the tree's canopy is maintained with annual mechanical hedging (Figure 18). This is an unrealistic expectation as grower experience and project trials showed yields reduced after year 12. This scenario is presented in '35 t/ha no hand prune' (dark blue line) and assumes that yield declines to 35 t/ha after year 13. To provide perspective, the cumulative cash flow budget for navel oranges yielding 40 t/ha fruit price at $650/t and 1.5 minutes per tree annual pruning is presented (red line). The cumulative cash flow of a navel orange scenario is positive but substantially less than the worst-case W. Murcott of 35 t/ha. Although the W. Murcott scenario has a harvest cost of $245/t, compared to navels at $85/t, the higher yield and fruit price of W. Murcott provide greater cumulative cash flow than navel oranges. If W. Murcott trees have an alternate bearing cycle, then the fruit price could be reduced to $700/t.

The 1-minute scenario for doorway pruning and one or 2 internal limbs for 1 minute per tree ($50/h pruning rate) assumes an increase of 5 t/ha. This improves cumulative cash flows (Figure 18). Other benefits are creating a doorway for improved picker access and spray penetration.

Intensive hand pruning

Intensively hand pruning W. Murcott mandarins is labour intensive, but produces higher yields than mechanical hedging and results in a tree that is easier to manage and harvest. There are many intensive pruning options, and the best is one that is adapted to the site conditions. Two main factors affecting the intensity and style of pruning are the amount of watershoots and tree vigour. Using an inappropriate strategy might result in reducing fruit-bearing canopy and yield. There are factors to consider such as the availability of labour, skill and whole farm cash flow. There are 3 main styles of intensive pruning: vase, triangular tree and cordon trellis flat tree pruning.

Management considerations, cash flow and labour

Cash flow is a major consideration because intensive hand pruning requires about 6–8 minutes of total pruning time per year on vigorous trees and about 1–2 minutes per year on medium vigour trees. If a vigorous tree requires a total pruning time of 8 minutes at $50 per hour (@ 667 trees/ha), this equates to a pruning cost of $3,700/ha. For a large 100 ha orchard, this equates to $370,000 per annum. Small orchards, or orchards with a mix of varieties and enterprises, can more easily absorb the extra short-term costs of using intensive hand pruning on a portion of their orchard. However, a large orchard predominately growing W. Murcott mandarins will be more financially challenged. An obvious solution is to stagger the pruning over 5–8 years.

Labour availability is a very important factor. Intensive hand pruning requires a commitment to manage and remove regrowth annually. Missing one year can result in excessive regrowth that shades the lower canopy, reducing the fruit-bearing capacity. The regrowth will be larger in the following season and extra effort and time will be required to remove it. This canopy might need a couple of seasons to fully recover. An example of pruning labour requirements is: if an intensive pruning program requires 1.5 minutes per tree prune in spring, a 3-minute prune/regrowth management in summer and a 3-minute prune/regrowth management in autumn, then on a 10 ha W. Murcott orchard, this equates to 21 one person work days in spring and 43 one person work days each in summer and autumn. Considering weekends and holidays, 2 people would be required to intensively prune a 10 ha W. Murcott orchard in the selected periods. On a 100 ha orchard, 20 people would be required.

An important consideration when adopting intensive pruning is the potential effect on yield and cash flow. Every farm and block are unique and might respond differently to various pruning intensities. It is strongly advised that growers do small trials to assess which style and intensity best suits their tree conditions. After a few years, the trial will show the most appropriate strategy.

Managing regrowth and tipping

Managing regrowth is an important aspect of intensive hand pruning, and it is done by removing excessive shoots or breaking the tips of shoots. It is done manually by rubbing small shoots or pulling off larger shoots. Leather gloves are recommended. The need and timing for managing regrowth are very dependent on the site and the amount and vigour of regrowth. It is also strongly influenced by labour availability. Although a guide is provided on a regrowth management program, the best option is one that is suited to the site conditions and trying some different methods on a few trees is recommended.

Size of cut and shoot removal

Large limb cuts produce more and longer watershoot regrowth than cuts on narrower diameter wood such as branches. The ideal situation is to have a pruning program that mainly makes cuts on narrow-diameter branches and watershoots. However, when converting a large unpruned tree to a well-structured tree, large cuts on poorly positioned or excessive limbs are inevitable. The amount of regrowth produced from these cuts will depend on the tree's vigour, but in most cases, substantial regrowth management will be required.

The appropriate number of shoots to leave behind is best determined from experience, i.e. thinning shoots of some trees at different intensities and observing the density of canopy towards the end of the season. As a starting guide, thin shoots to about a handspan apart on limbs and large branches; on cuts smaller than 20 mm in diameter, thin shoots down to 2–3 shoots. If the regrowth response is very vigorous, then regrowth tipping might be required (discussed in oncoming sections).

Managing regrowth timing

There are pros and cons for managing regrowth at various times throughout the season. Each timing can be better suited to several types of regrowth responses. The availability of labour is also a significant factor when determining when to manage the regrowth.

Managing early regrowth (late spring)

Managing regrowth in late spring when it is about 200–300 mm long has the advantage of reducing competition between shoots and allowing the selected shoots to grow with adequate sunlight and resources. This can produce good results in medium vigour trees as minimal further regrowth will occur. Managing regrowth when it is young (200–300 mm long) is important because tipping shoots that have grown too large is less effective than when they are in the early stages of expansion.

In high vigour trees, managing regrowth early (e.g. spring) might induce another sprouting of new shoots that will require further management. In some situations, allowing this regrowth to grow produces a cluster of competing weak shoots that eventually get shaded from watershoots and die back.

Managing mid-season regrowth (mid-summer)

Managing regrowth in mid-summer when shoots are about 500–700 mm long has the advantage of enabling a better selection of watershoots for removal and retaining medium-size shoots for next season’s flowering and fruit set. With a medium regrowth response, this can be suitable but with a very high vigour regrowth response, it might be too late to get the best effect from shoot tipping. It is also the hottest time of the year and the least comfortable for labour.

Managing autumn regrowth

Managing regrowth in autumn is the most favourable time because any new regrowth will be slowed down by cooler temperatures. It is also a less busy time of the year, thus improving labour availability. Autumn pruning would remove watershoots and excessive regrowth. In some situations, the regrowth might be too vigorous and require earlier intervention.

Another advantage of managing regrowth in autumn is that openings in the canopy are sustained throughout harvest. Improving light penetration allows the fruit to improve in colour development throughout the tree.

Pruning a tree in spring will increase the growth of new shoots during the fruit drop period and it is speculated that this might increase the risk of excessive fruit drop. The hormones produced from the growing shoots, or the increase in the carbohydrate sink of new shoots, might increase fruit drop and decrease yield. Field observations have shown some instances of increased fruit drop after late-season pruning, but there have been many instances where this has not occurred. It is either a coincidence, or there are other factors contributing to pruning near flowering and fruit drop. Pruning and managing regrowth in autumn will reduce the intensity and time of spring pruning (most of the undesirable wood was removed in autumn), thereby reducing the risk of excessive fruit drop from a heavy spring prune.

High vigour trees: pruning and regrowth management issues

On vigorous trees most regrowth can be watershoots. If all these watershoots are removed, then there is little canopy remaining for the following season's crop. The high level of regrowth removal induces another high regrowth response. This is enhanced by the lack of substantial yield to absorb carbohydrates produced by leaves, i.e. carbohydrate production by leaves is no longer adsorbed by fruit but provided to shoots for more vigorous growth. Maintaining a tree with optimal yields (45–65 t/ha) helps minimise regrowth vigour.

Alternate bearing can be exacerbated or alleviated by pruning. Intensive pruning in years of high crop load will encourage more shoot growth for the following season's crop. However, as discussed in the ‘severe hedging’ section, severe pruning (e.g. half tree) induces a heavy regrowth response on the cut part of the tree that will crop in the second season and could induce alternate bearing.

In Australia, it is speculated that shoots arising from cuts conducted before early December can bear fruit in the next season. Information from South Africa suggests that shoots arising from cuts made before February can produce flowers and fruit. Research needs to be conducted to understand the relationship between pruning intensity and timing to the propensity of the growth to bear fruit in the following season.

Regrowth tipping: transforming watershoots

In recent years intensive pruning (triangular style) has been gaining popularity in South Africa. Row access is an issue, especially with trees with a row spacing of less than 6 m. Thinning and tipping regrowth are used to keep the canopy compact and productive.

Tipping is breaking by hand or cutting with secateurs the top portions or half of a 200–300 mm shoot (Figure 19) so at least 3 buds remain (e.g. 3 leaves). Two to 3 shoots will sprout and are tipped again when they are about 200–300 mm long. With 2 tipping sessions, one watershoot can be converted into a complex branch of 9 shoots. A tipping session could take 3 minutes for a tree that has been intensively pruned for the first time and 1 minute for trees with a medium to low amount of regrowth. A third tipping exercise might be required. Videos of a 2022 study tour where South African growers and tour participants show and discuss shoot tipping and other crop management topics are available on the DPIRD website, (https://www.dpi.nsw.gov.au/agriculture/horticulture/citrus/content/canopy-management/mandarin-pruning2/south-africa-w.murcott-canopy-management-study-tour).

Multiple tipping sessions of trees with high amounts of vigour can be expensive. Two tipping sessions at 3 minutes per session can cost about $2,500/ha (6 min per tree @ $35/h @ 550 trees/ha, plus $500/ha in mulching). However, if this results in a 10 t/ha increase in yield, then this will provide a net gain of $4,300/ha (@ $680/t).

Project trials to manage the regrowth in mid-summer when shoots were about 1 m long were unsuccessful. This was too late because the cut shoot sprouted one or 2 watershoots and tipping early in late spring produced more compact growth.

Figure 19. Tipping shoots during early growth (200–300 mm shoots, late spring to summer) promoted side shoots to grow. The side shoots reduce the vigour and length of the shoot, converting a single shoot (possibly a watershoot) into a productive complex branch. This branch can produce flowers and fruit in the next season. The red circle surrounds the break-point of a tipping conducted in early spring (4 months prior).

Progressive changes in managing regrowth

A large tree that has been intensively pruned in late winter will produce an extensive amount of regrowth. This regrowth will need to be managed during spring and possibly throughout summer and autumn. Each pruning session could take up to 3 minutes per tree.

In the following season, once a desired limb structure is developed and no large limb cuts are required, pruning cuts will be less intensive and on smaller-diameter wood. This will produce less regrowth than in the first year and the time taken on managing regrowth will decline by about half.

Converting a large tree to an intensively pruned structured tree over numerous years will spread the gradual decrease in time required to manage the regrowth over those years.

Intensive vase tree pruning

A vase limb structure has 7–9 limbs growing from the base of the tree. Vase pruning is suitable for row spacing 6 m and wider. The limb structure from the first third of the inner part of the tree will probably have upright limbs (Figure 20).

Regrowth emanating from the first-third inner part of the tree is mostly removed annually because there is a narrow space for the fruit to grow, and allowing too much regrowth to remain will quickly clutter the centre of the tree. Fruiting wood is encouraged and managed on the outer two-thirds of the tree, where limbs have a 45-degree to horizontal growth angle. Horizontal limbs have a greater capacity to generate shoots than upright limbs because horizontal shoots have less apical dominance. The height of the tree is managed by hand pruning (Figure 21, Figure 22, Figure 23). The maximum height of major limbs is kept at about the maximum height pruners can reach to manage regrowth (e.g. 2 m).

Managing regrowth is critical to the success of intensive pruning. If the regrowth is medium, then it might only require pruning in autumn, but if regrowth is vigorous and extensive, repeated pruning sessions might be required. If most of the regrowth is watershoots, then the tipping method is recommended.

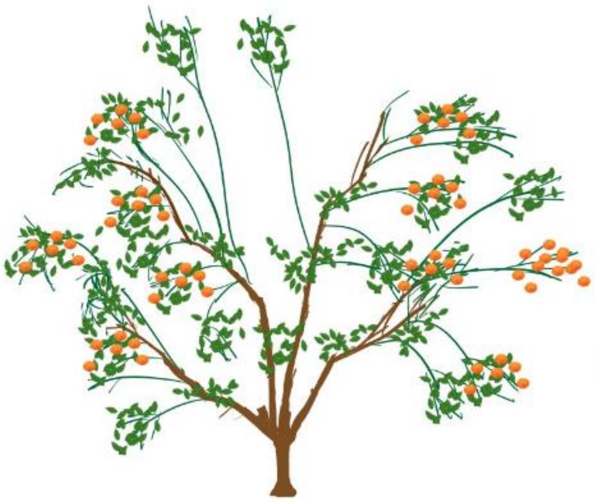

Figure 20. W. Murcott grown in a vase-shaped pruning style.

Figure 21. Left: W. Murcott trees managed by mechanical hedging by Ryan Arnold (Payap Produce, South Australia). The trees were tall, the fruit were setting on the upper parts of the canopy, the yield was low (average 35 t/ha) and it was difficult to pick fruit high up in the canopy. Right: the trees were intensively pruned into a vase shape and an extensive amount of regrowth occurred that required shoot thinning.

Figure 22. Left: the W. Murcott trees after the second year of pruning and regrowth management. Right: the trees produced a medium yield the first year after pruning (40 t/ha), but in the proceeding years, the trees averaged 50 t/ha. The cost of pruning and managing the trees is about $8 per tree, the yield has increased from 35 t/ha to 50 t/ha (net gain of about $5000/ha) and the harvest cost has been reduced from $120/t to $90/t (easier to pick).

Figure 23. An intensively pruned W. Murcott tree that is 2.4 m high has fruit that is easily accessible through the upper and lower parts of the canopy.

Intensive triangular tree pruning

Triangular tree pruning forms a tree with a single wide layer at the bottom third of the tree and a central leader (sometimes 2 or 3) to form a narrower top layer of the tree (Figure 24). It is becoming popular in South Africa because it creates a narrow canopy that allows tractor access, maintains yields between 45 and 65 t/ha, allows access for workers to conduct canopy and crop manipulation and improves spray penetration. A series of videos are available on the NSW DPIRD website showcasing growers in South Africa using the triangular tree canopy management system.

Figure 24. Left: A W. Murcott tree grown in a triangular or pyramid shape pruning style. Right: triangular shape trees in South Africa. The narrow canopy provides enough inter-row space between the trees for good light interception and tractor access.

A key feature of the triangular pruning system is shoot tipping (described in the regrowth management and tipping section) to keep the canopy compact and eliminate watershoots. Two to 3 shoot tipping and watershoot removal sessions, each requiring 1.0–2.5 min per tree (667 t/ha), are conducted throughout spring and summer. In South Africa, labour is about AU$1.50/h and it is very cost-effective for potential 20 t/ha gains in yield and improved orchard management.

There is little experience of triangular tree pruning in Australia. A cost-benefit analysis of triangular tree pruning, based on South African information, is as follows.

If spring pruning for a 5.5 m × 3 m (606 trees/ha) W. Murcott orchard using a triangular tree pruning style is 2.5 minutes per tree followed by 3 sessions for managing regrowth at 2 minutes per tree, then the total time for pruning and managing regrowth is 8.5 minutes per tree or $3,005/ha (@ $35/h labour). If yield improves by 20 t/ha at a $562/t fruit price ($800/t farm gate price minus $238/t harvest cost; harvest cost $100/bin), then the increase in income will be $11,240/ha. This is a net increase of $8,235/ha and also results in improved spray penetration, less alternate bearing, better-sized fruit, improved harvest safety and access to supply of harvest labour (pickers favour orchards with medium height, easily accessible trees; less ladder work and a higher daily bin picking rate). The improvement in yield required to break even with this annual pruning scenario is 5.4 t/ha ($3,005/$562). A conservative breakeven estimate that accounts for extra unaccounted costs is 6 t/ha. Based on current knowledge and field experience, a 6 t/ha increase in yield is a reasonable expectation from intensively hand pruning navel or mandarin trees.

It can take 3–6 years to gradually transform an unpruned tree or vase-shaped tree into a triangular tree shape. Pruning too much too quickly might induce an excessive tree vigour response. A recommended approach is to hedge trees down to, or near, the optimum height (e.g. 2.0 to 2.4 m) to allow light into the tree and encourage shoot growth in the inner canopy (Figure 25), and remove one poorly positioned limb. Apply the appropriate regrowth management style to the tree's vigour response. In most situations, a vigorous growth response is expected, and some or all elements of shoot tipping and watershoot removal will be required to keep the canopy compact. The top of the tree will respond with vigorous growth at the cut limb. It is not worthwhile to manually manage the regrowth on upper limbs because they will eventually be removed. Mechanically hedging the regrowth on the top of the tree a second time in the season is an economically more efficient solution than manually managing the regrowth. Over time, unwanted limbs are manually removed and the regrowth from the cuts will need to be managed. Cutting back more limbs during a single season will transform the tree more quickly, however, more time will be needed to manage the regrowth than spreading limb removal over a longer time.

Figure 25. Evan Gardener (Costas, South Australia) is converting trees previously managed by annual mechanical hedging to an intensively pruned triangular tree shape. Evan recognises that triangular tree pruning needs to be adapted to Australia's labour prices by using mechanical hedging for some operations and rationalising regrowth management. The first stage was topping the trees to 2.4 m to encourage canopy growth at lower layers. The trees were topped in early summer; the photo was taken in April. After harvest, Evan plans to remove the shoulders of the upper protruding limbs to develop a more triangular tree shape.

Cordon trellis flat tree pruning

Dean Morris is a citrus grower and production consultant (Moricom) in the Riverina who has been successfully growing W. Murcott mandarins on a trellis structure since 2007. Dean grew W. Murcotts on a 6-wire 3 m tall trellis at a 3.8 m row spacing (Figure 26) in a flat 2-dimensional shape to overcome the yield decline typical in conventional orchards. This method is attractive to harvest labour because the trees are easy to pick using a picking platform. Other operations, such as pruning and spraying, are also easier and more efficient.

Figure 26. Left: Dean Morris checking the canopy of W. Murcotts grown on the 6-wire trellis structure. Right: 2-year-old trees grown on a one-wire trellis structure.

The end trees on the 6-wire trellis did not have a wire high in the canopy because they were planted next to the anchors. Dean noticed these trees grew upright limbs that produced canopy and fruit; they formed their own upright trellis structure without wires. The limb positions of the tree were similar to a cordon training style. The 6-wire trellis structure is expensive and growing free-standing trees that form a narrow canopy without a trellis has a significant economic advantage (6-wire trellis costs $28,000/ha; one-wire trellis costs $3,000/ha).

A single wire trellis was used to help quickly establish the horizontal base arms of the tree and then 4 upright cordons were selected to be trained upright to be the structural limbs (Figure 26). Yields to date have been comparable with conventional high density W. Murcotts with the advantage of improved yield longevity and efficient management.

Economics of intensive pruning and overhead netting

Various W. Murcott production scenarios were analysed and the results are presented in Figure 27. The graph presents cumulative cash flow for various W. Murcott scenarios. Cumulative cash flow is explained in the 'economics of mechanical hedging'.

The scenario assumptions are: 667 tree/ha planting density, a fruit price of $800/t for field-grown non-pruned trees fruit (field), $850/t fruit price for field-grown pruned trees (field), $1,000/t fruit price for protected cropping (net), $120/bin (420 kg bin) to harvest non-intensively hand-pruned tree and $100/bin to harvest intensively pruned trees. The intensive pruning scenarios had one-wire trellis and vase-pruned with regrowth management (RGM). All other scenarios assume trees are mechanically pruned, except the mechanically hedging treatment that includes a 1-minute doorway and inner limb hand pruning (+1 m prune).

For reference, the mechanically hedged 35 t/ha (grey line) and mechanically hedged 40 t/ha plus 1 min annual doorway and inner limb pruning (light brown line) originally presented in Figure 18 are also presented in Figure 27.

The 2 highest cumulative cash flow scenarios are the protected cropping (net) vase pruned regrowth management (RGM, red line) and the one-wire trellis systems (dark brown line). The triangular tree pruning system is not presented because there is little experience with it in Australia and it is speculated that costs will be similar to the vase pruned RGM production system. The main reason the RGM and one-wire scenarios have the highest cumulative cash flows is because they have a higher fruit price ($1,000/t) when grown under hail netting (protected cropping) compared to open field production ($800/t). The nets reduce the velocity of wind, resulting in reduced levels of wind blemish, a higher first-grade pack-out and overall fruit price. The nets also accelerate early tree growth, and the budgets assume the netted tree provides yields one year in advance of field-grown trees. However, growing under netting has a higher prevalence of pests and an extra $250 per annum for pest management and an extra 1 minute per tree in hand pruning are added. Growing under netting requires a higher and more frequent level of pest and canopy management monitoring and skill. If pests and the canopy are not adequately managed, it can quickly result in downgrading fruit prices or rapidly declining yields that take numerous years to return to regular levels.

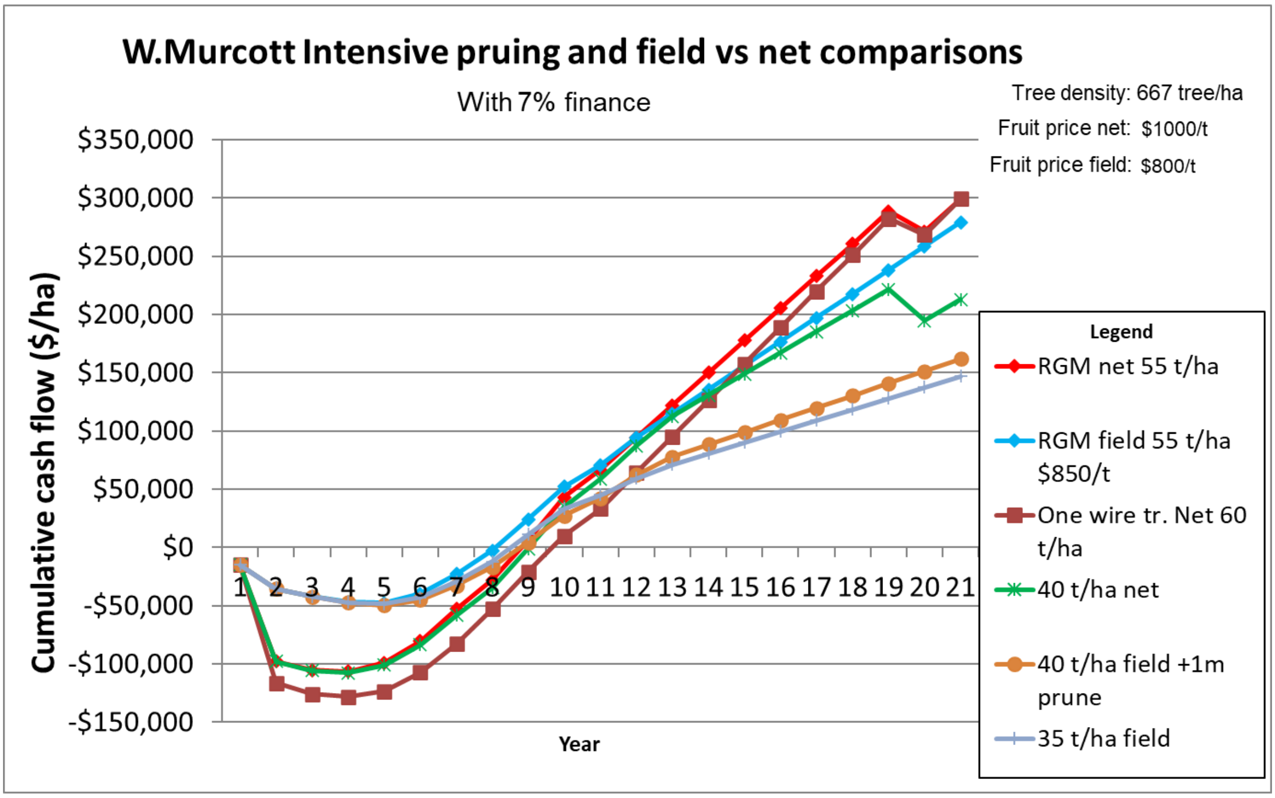

Figure 27. W. Murcott intensive pruning production scenarios.

The RGM field ($850/t fruit price, light blue) and 40 t/ha mechanically pruned under nets ($1,000/t fruit price, green line) scenarios had similar cumulative cash flows from years 10 to 19. However, from year 20, there is a dip in the cumulative cash flow of the 40 t/ha mechanically pruning under nets because the nets needed to be replaced.

The analysis infers that the use of netting and intensive pruning complement each other because the extra yield gained from intensive pruning amplifies the income returned from the higher fruit price.

Growth regulators and crop regulation

Growth regulators and crop regulation were not part of the project scope, however, the use of growth regulators in South Africa was documented on the study tour. A more detailed report and videos from the South Africa study tour are available from the NSW DPIRD website.

Many growers in South Africa use uniconazole (Sunny®) as a soil drench, which is applied during flower induction (late April–early May) to increase flower numbers, and at early spring flush (about 20 mm) to reduce flush elongation (reduce pruning) and increase fruit set.

Gibberellic acid is used at 80–100% petal fall to increase fruit set.

Dichlorprop-p and 3,5,6-TPA are used to thin fruit and increase fruit size. To assess if fruit thinning is required, the total number of fruit on a couple of representative trees is counted by stripping the tree of fruit. It is common for trees to set about 1,500 fruit, requiring about 700 fruit to be removed. Fruit diameter is regularly measured so the chemical thinner is applied at the optimum timing to eliminate the targeted number of fruit within the smaller size range. Chemical thinning might reduce 200–400 fruit per tree and the rest is removed by hand thinning in January.

A video of internationally renowned citrus researcher Paul Cronje (Citrus Research International) discussing growth regulators is available on the NSW DPIRD website.

Further resources

Other research

A research project studying the physiology of alternate bearing of W. Murcott mandarin has been completed in South Africa at Stellenbosch University by Jacobus Stander (Stander et al. 2018). The study found that crop load is influenced by flowering intensity and one of the most important factors was the amount of vegetative growth during the previous season. During a high crop load, vegetative growth is suppressed, reducing the number of flowering sites in the following season. The study also found that in an 'off' year, tree carbohydrates are depleted, and leaves had a higher concentration of indole acetic acid (IAA). The treatment of gibberellic acid helped to suppress flowering during an 'on' year and uniconazole-P (Sunny®) helped to increase flowering for an 'off' year.

Stander OP, Barry GH and Cronje PJ (2018). Fruit load limits root growth, summer vegetative shoot development, and flowering in alternate-bearing ‘Nadorcott’ mandarin trees. *Journal of the American Society for Horticultural Science*, American Society for Horticultural Science, 143: 213–255, 10.21273/jashs04438-18.

Project videos and publications

Videos are the best way to extend canopy management information because they offer a 3-dimensional view and a visual explanation. 46 videos were generated in the project and these are on the citrus canopy management tab of the NSW DPIRD citrus website.

https://www.dpi.nsw.gov.au/agriculture/horticulture/citrus/content/canopy-management

The videos are on the following topic areas:

- Queensland mandarin pruning (4 videos)
- Spain study tour (18 videos)
- South Africa study tour (6 videos)

- Project pruning treatment descriptions (12 videos)
- Western Australia W. Murcott and Imperial pruning case studies (4 videos)
- Dean Morris pruning case study – trellis
- Pyap Produce intensive vase pruning

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