

Maximising the light interception and productivity of Australian apple orchards

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1 The impact of light interception and distribution on yield and fruit quality

Apple orchard light interception and distribution are the keys to high yields and fruit quality.

Sunlight intercepted by leaves provides the energy to drive the process of photosynthesis, which is fundamental to the growth and fruiting of all plants, including apple trees. Without the capture of sunlight, trees cannot manufacture the carbohydrates and food required to produce high yields of good size, well-coloured, high quality apples.

The aims in the planting and management of an orchard are to:

1. Create and maintain a desirable tree form (height, shape, spread, Tree Row Volume, leaf area) that intercepts approximately 60% of daily sunlight in midseason
2. Ensure sufficient light can reach all parts of the canopy.

Although the light intensities where apples are produced in Australia are high relative to other apple producing regions throughout the world, many commercial orchards are not attaining their full yield and fruit quality potential.

Low productivity in Australian apple orchards is due to either (a) insufficient canopy volume (Tree Row Volume) or (b) excessive tree vigour and internal shading.

Research trials consistently show that apple orchard yields increase as midseason light interception increases to 60%. A point is reached beyond this (eg. 70%) where the canopy is too dense or excessive tree spread and height lead to severe shading effects, with subsequent declines in fruit quality and yield. Internal tree shading can severely reduce yield, fruit size, colour and sugar content.

To summarise, the two basic principles of apple orchard system design and tree management for highest yields and packout are:

1. Maximise light interception for high yields (aim for 60% midseason light interception)
2. Maintain good light distribution within the tree canopy for high fruit quality and packout (high marketable yield).

The easiest way to achieve these objectives is to use trees on dwarfing rootstocks planted at high densities (above 1900 trees per hectare). Modern intensive planting systems must be designed to intercept high levels of sunlight early in the lifetime of the orchard, to help produce the yields and fruit quality needed to offset orchard establishment costs as quickly as possible.

2 *Tree Row Volume (TRV)*

The maximum potential light interception of a particular orchard system is fixed, and determined by canopy geometry ie. tree height, spread, shape, alleywidth and planting density.

Tree Row Volume (TRV) provides a measure of this, and is calculated as a volume of canopy (m^3 per hectare) from measurements of tree height, canopy spread and row spacing.

Estimates of Tree Row Volumes required for maximum yields are:

Intensive orchards	> 1900 trees/ha	10 000 to 12000 m^3/ha
Semi-intensive orchards	1000 to 1900 trees/ha	12 000 to 15000 m^3/ha
Extensive orchards	< 1000 trees/ha	18 000 to 20 000 ⁺ m^3/ha

(as provided in the notes for the second Future Orchards 2012 orchard walks in Nov 2006).

Whilst TRV defines the upper limit of light interception (and potential yield) for a particular orchard system, it is how the trees in the system fill that volume that ultimately determines the marketable yield of that orchard.

At one extreme, trees for a given TRV may have a sparsely developed canopy, with too few leaves to intercept sufficient light to achieve high yields. This is common in many Australian apple orchards.

At the other extreme, the canopy volume may be densely packed with vigorous shoots and leaves which internally shade the tree, severely reducing apple set (yield) and fruit quality. It is counterproductive if the tree canopy volume consists primarily of vigorous shoots.

Ideally the Tree Row Volume will be filled by a high proportion of evenly spaced branches supporting fruiting spurs that are exposed to adequate sunlight, balanced with new extension shoots primarily 30cm or less in length.

3 *Leaf Area Index (LAI)*

Leaf Area Index (LAI) gives a good guide to how trees fill their allotted space, and is calculated as m^2 leaf/ m^2 orchard floor surface area. Unfortunately, LAI can be difficult and time-consuming to measure.

As tree density increases, the leaf area per tree required to achieve a particular level of LAI declines (table below). In other words, at higher tree densities, individual trees require less leaf to adequately fill their allotted space and to achieve midseason light interception of 60%.

Leaf area (m² per tree) required to achieve a particular LAI

	1250 trees/ha (4m x 2m)	2000 trees/ha (4m x 1.25m)	2500 trees/ha (4m x 1m)
LAI = 1.0	8 m ² leaf	5 m ² leaf	4 m ² leaf
LAI = 2.0	16 m ² leaf	10 m ² leaf	8 m ² leaf
LAI = 3.0	24 m ² leaf	15 m ² leaf	12 m ² leaf

4 *The light interception and productivity of Australian apple orchards*

In a project over four years, the light interception, leaf area index (LAI), yield and fruit quality of 120 apple orchard systems was measured in orchards throughout Australia.

These included a wide range of varieties, rootstocks, planting densities, tree vigours and tree ages, representing a broad cross-section of the current systems used in Australia. Tree densities varied from traditional wide-spaced vase trees (270 trees/hectare) to ultra-high density 'V' trellis double-row systems of up to 10 000 trees/hectare. Varieties included Royal Gala, Hi Early Red Delicious, Red Fuji, Cripps Pink and Cripps Red, and rootstocks included Northern Spy, MM.104, MM.106, M.26, M.9 and Ottawa 3.

At all sites across Australia the close relationship between light interception and yield was evident. Light interception and LAI provide good guides to apple orchard productivity.

The LAI of orchards ranged from 0.5 to over 3.5, and the highest mid-season diurnal (daily) light interception measured was 69-70%.

Despite the wide range of varieties, rootstocks and planting densities evaluated, the most productive systems (regular annual yields of 50 - 88 tonnes/hectare) were characterized by:

- Diurnal midseason light interception of 55-62%
- LAI of 2.0 to 3.0
- North/south row orientation
- Tree densities of 1500 – 2900 trees/ha (most were 2000 – 2900 trees/ha).

Several important trends should also be noted:

- Yields increased as light interception increased from 55 to 62%
- Marketable yields increased as LAI reduced from 3.0 to 2.0
- Marketable yields improved as tree height reduced from 1.2 times to 1.0 times row space (4.5 to 3.5 metres in a 3.5m row space).

Apple orchard productivity was consistently high for systems with mid-season diurnal light interception of 60% and LAI close to 2.0. Due to internal shading effects, there was a gradual decline in fruit size and colour (marketable yield) as LAI increased significantly above 2.0.

Orchard productivity also declined as LAI decreased below 1.5. Trees with LAI <1.5 have insufficient canopy volume for high light interception and yields, and produce a high proportion of apples susceptible to sunburn through exposure to radiant heat.

The problem of insufficient light interception is common throughout Australia, with many systems having low LAI and inadequate canopy development. A majority of orchards in Australia intercepted less than 60% of diurnal midseason sunlight. This was commonly due to inadequate Tree Row Volume as a consequence of trees being planted too far apart within rows, and/or alleyways being wider than necessary.

Where the light interception and LAI of mature trees is too low, it is difficult to substantially improve productivity. Incorrect rootstock and tree density decisions made at planting cannot be changed a few years later, unless the orchard is totally replanted. This is costly and impractical.

5 *Row Orientation*

North/south row orientation should always be used where possible. The potential light interception by trees in north/south rows from October to early March is always higher (up to 15-20%) than equivalent trees grown in east/west rows.

The light distribution in east/west rows is also poor. Apples on the upper northern side of east/west rows are susceptible to sunburn through exposure to excessive radiant heat. In addition, the potentially low light levels on the southern sides of east/west rows can lead to low yields in these parts of the trees, and small, poorly coloured fruit.

The unbalanced light distribution of east/west rows becomes worse as LAI and tree height increase, and as alleyways become narrower. The deficiencies of east/west rows were particularly obvious at sites in Tasmania, SA and WA.

Row orientation is less of an issue in orchards of lower tree vigour and LAI. In some regions such as the Adelaide Hills, the planting of east/west rows may be unavoidable due to the local topography. In these situations it is essential to ensure that LAI does not exceed 2.0, and that the suggestions for orchard design in the “Vision” later in these notes are followed.

6 *Tree Height*

Increasing tree height has less effect on light interception than planting density and LAI.

Light interception is increased with taller trees and narrower alleyways, but a point will be reached where yield and apple quality decline as a result of internal shading and poor light distribution.

Studies have shown that in an orchard with a row space of 3.5m, increasing tree height by 50% from 3.0m to 4.5m, increases potential light interception by just 6-10%. Although this

can lead to small yield improvements, any gain is often at the expense of marketable yield and fruit quality, low in the canopy.

It is generally accepted that to maximize marketable yield, tree height needs to be between 0.8 and 1.0 times the between row space.

Relatively low light interception frequently occurs in orchards with trees of above 4 metres height. Tall upright trees are inefficient at intercepting light, particularly if strong upright branches are allowed to develop in the upper tree. Such orchards tend to have unintercepted light penetrating to large areas of the orchard floor, and tall shaded trees with dense canopies and poor internal light distribution.

Increasing tree height above the between-row space, contributes relatively little to total light interception, whilst providing unnecessary leaf area that shades lower regions of the tree.

Additionally, as tree height and canopy density increase, the fruiting zone and productive wood is pushed to the upper and outer regions of the canopy. Trees then have a large volume of unproductive canopy. This increases the costs of pruning and harvesting and contributes to spray coverage problems.

The effect of increasing tree height is worse at higher LAI, and less of an issue when trees are of lower vigour and leaf area.

At times of the day when shadows are long (early morning and from mid-afternoon onwards), taller trees will have higher light interception, but cast their shadows across alleyways and into adjacent rows.

During the middle part of the day (one or two hours either side of solar noon) increasing tree height has little effect on light interception, but can contribute to internal shading and poor light distribution within the canopy as sunlight has to pass through a greater depth of canopy to reach the orchard floor.

Unintercepted light that completely misses trees is a 'wasted' resource.

Yield and fruit quality gains are best achieved by maximising the orchard surface area covered by the external fruit producing canopies of trees, not by increasing tree height beyond the distance between rows.

High density plantings of shorter trees have a larger external surface area exposed to light, and a lower volume of "poorly illuminated" canopy than lower-density plantings of tall trees.

Alleyways are an essential yet inefficient feature of orchards, representing areas of land that are non-productive. Despite this, the contribution of alleyways in providing 'gaps' for light penetration in the orchard is important and shouldn't be under-estimated.

7 *Tree Vigour*

Maintaining a narrow canopy depth in all the directions from which sunlight may be coming is a sound principle that is a feature of many apple orchard designs, including Tatura trellis,

‘V’ trellis, Vertical Axis and Spindlebush systems. The more leaves there are above or outside a certain point in the canopy, the less likely it is for light to reach there. Hence, in productive orchards all fruit-bearing regions are never far from an outside surface of the tree.

Where trees are over-vigorous with light interception >60% and LAI approaching 3.0 and above, marketable yields will improve with control of tree vigour and attention paid to individual tree structure, pruning, leaf distribution and branch orientation. Vigour control techniques such as summer pruning, trunk girdling, root pruning and regulated deficit irrigation (RDI) may be appropriate in these situations.

Reductions in tree height from >4.0 metres to 3.0 metres will reduce light interception early and late in the day, but also reduce the effects of cast shadows across alleyways into adjacent rows. It is far more desirable and efficient to increase light interception with shorter trees at higher densities, than with tall trees.

Heavy pruning and/or the application of additional water and fertiliser are undesirable tree management options, which in most cases will have little beneficial effect on the vigour and productivity of mature trees, and will more likely reduce yield and fruit quality.

Similarly, crop load adjustment on dwarf trees will have little influence on improving their growth and vigour once they are mature and have cropped for several seasons and “spurred up”.

Even in “well-illuminated” trees where considerable light penetrates the canopy and reaches the orchard floor, light measurements show that some parts of the tree receive less than 10% of incident sunlight levels throughout the day. At such low light intensities, fruit set and quality is poor and trees require restructuring to open up the canopy.

8 *Tree Density*

In the early years of an orchard planting, the higher the tree density, the higher the light interception. Hence the potential for higher yields and earlier return on investment.

As trees age and fill their allotted space, planting density becomes a less critical factor influencing light interception. For high density planting systems to be productive and economically viable, they must therefore intercept a very high proportion of incoming solar radiation within the first three years of planting. If not, their full potential advantage is lost at considerable cost through the purchase and planting of high tree numbers.

Using high tree densities and dwarfing rootstocks is a simple way to achieve the desired TRV and LAI early in the lifetime of the orchard, whilst being able to grow “calm” trees that rapidly fill their allotted space and can simultaneously produce fruit.

The higher the tree density, the less canopy volume an individual tree needs to fill, and the less demand is placed on the tree to produce a lot of growth to fill the TRV.

For example:

At 5m x 2m (1000 trees/ha) each tree has an allocated orchard floor area of 10m² to occupy.

At 4m x 1m (2500 trees/ha) each tree has an allocated orchard floor area of 4m² to occupy.

Tree densities of 2000 to 3000 trees per hectare are suggested.

Planting trees at very high densities (eg. 5000 trees/ha) is not recommended. The cost of trees is prohibitive, vigour management can be a problem as the trees age, and research trials in Australia to date show that the marketable yields from systems planted at 2000 to 3000 trees/ha are as good or better than at 5000 trees/ha.

‘V’ trellis systems potentially permit higher tree densities than standard vertical trellis systems. The productive canopy volume of trees on ‘V’ trellis can be spread over a larger orchard floor surface area than is possible with upright vertical axis or tall spindle trees.

Research trials in SA and Qld are currently comparing “open” ‘V’ trellis systems at 3555, 4444 and 5925 trees/ha with standard vertical trellis systems at 2000, 2500, 3333 and 5000 trees/ha.

9 Rootstocks

The use of dwarfing rootstocks (eg. M.9, Ottawa 3, M.26) is ESSENTIAL to success with high density plantings.

Trees on vigorous rootstocks will fill their allocated space quickly, but this will be at the expense of good light distribution, yields and marketable yields as the orchard ages (year 4 onwards).

The more vigorous the rootstock, the greater the potential decline in marketable yield as the trees age. This is particularly true of “light-sensitive” varieties such as Cripps Pink and Galaxy. Trees on vigorous rootstocks are NOT going to suddenly switch from “growing” mode to “fruiting” mode in year 3. just because you want them to!

You will be far better off (financially and in ease of tree management) if you use dwarfing rootstocks that have a tendency to produce fruit rather than to produce excessive growth.

Dwarfing rootstocks planted at high densities have many advantages over vigorous rootstocks, which include:

- The ability to fill the orchard floor area quickly (high light interception by year 3 through increased tree numbers rather than through excessively tall trees with dense canopies)
- Precocity (the ability and tendency of the trees to produce fruit rather than excessive shoot growth)
- Higher yields early in the lifetime of the orchard
- Higher volume of “well illuminated” canopy
- Smaller canopy volume of individual trees, with all fruit close to external regions of the tree
- Higher marketable yields and packout
- Ease of vigour control, especially as the trees become older

- Improved efficiency of standard orchard operations (spraying, pruning, thinning, harvesting).

10 A vision for Australian apple orchard design to maximise marketable yields

In planting and managing an orchard, always begin with the end in mind. What is your vision and goal for the orchard block in 5 years time? 10 years time? Picture how you want your orchard to look.

A suggested ‘vision’ to aim for in apple orchard system design for high yields and fruit quality is:

- Midseason diurnal light interception of 60%
- LAI of close to 2.0 and not so low that there is excessive fruit sunburn
- Tree height of approximately 0.8 to 1.0 times between row spacing
- North/south row orientation
- Trees are discrete units with a well-defined leader (whether grown in single-rows or as part of a ‘V’ trellis system)
- Tree tops that do NOT merge, and are separated by ‘gaps’
- A narrow canopy depth in all directions from which sunlight is incident throughout the day.

A good guide to the light interception and potential productivity of your orchard is to look at the cast shadows of the trees in mid-morning or mid-afternoon on a sunny day in mid-season (December to February). The external outlines of the trees will be easily visible in the alleyways.

- If the cast shadows are small and most of the orchard floor is in full sunlight, the TRV is too low.
- If the tree shadows consist of solid blocks of darkness then the canopy is too dense, and poor light penetration and distribution in the canopy will be reducing marketable yields.
- A speckled pattern of light and dark areas within the outline of the cast shadow indicates that there is good light penetration and distribution within the trees.

Correct selection of rootstock and tree density at planting is crucial to the success of an orchard system. If the LAI and light interception of mature trees is too low, poor orchard productivity will be difficult to correct. If LAI and light interception are excessive, vigour control and attention to tree structure will help lift yields and fruit quality.

Under Australian conditions, the primary objective of apple orchard system design should be to achieve midseason diurnal light interception of 60% as early in the lifetime of the orchard as possible (preferably by year 3 or 4).

Ideally this should be done using a high density system with moderate rather than excessive tree numbers, but not so few trees or too vigorous a rootstock that it becomes difficult to switch the trees from “growth” mode to “fruiting” mode and control their vigour once they have filled their allotted space.

The high value apple varieties currently grown such as Cripps Pink, Red Fuji, Imperial Gala, Galaxy etc must all meet specific blush requirements. To grow these varieties in systems that intercept more than 60% of diurnal midseason sunlight is too likely to be at the expense of fruit colour, quality and packout through shading.

Low yields in Australian orchards are generally due to inadequate light interception, however many of the newer high density systems (including ‘V’ trellis) are approaching 60% light interception as early as their third leaf. The development of an adequate tree canopy is especially important in the early management of high density systems under the high light intensities and temperatures experienced in Australian apple producing regions.

11 Conclusions

- Aim to make EVERY apple contribute to your profit.
 - To produce high yields but low packout through poor apple size, colour, fruit quality is a waste of your valuable time and money, and a waste of the tree’s resources.
- Sunlight is FREE
 - Aim to capture 60% of daily midseason sunlight as early as possible in the lifetime of the orchard (Tree Row Volume), whilst ensuring that all regions of the canopy are “well-illuminated” to produce high quality apples (Leaf Area Index).

12 Further Reading

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