High Density Avocado Production

Constructing an Integrated Management Model

A report for

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Executive Summary

The Australian avocado industry is approaching a tipping point where supply could outstrip domestic demand and in the absence of any significant export activity, producers could face declining profitability. In addition, increasing land prices and decreasing availability to good quality water resources are forcing industry stakeholders to search for more productivity from existing assets. This has been identified by the industry as one of four pillars of their Strategic Investment Plan, with the outcome being a 10% increase in productivity per unit land area.

One of the ways that this could be realised is through intensification of production. Australia lags behind other countries in this regard having an average of 219 trees/ha compared with the Chilean industry average of between 800 and 1,000 trees/ha and some plantings of up to 6,000 trees/ha. Intensification is not without its challenges and the purpose of this study was to investigate the current state of global high density production and to assimilate that knowledge into a simple integrated model for implementation in Australia given the unique challenges that the local industry faces.

It was found that uptake was driven by factors other than productivity gains and without these strong drivers, change was not forthcoming. In addition, implementation was complex and management intensive and current varieties and rootstocks were not well suited to high density production. However, tools do exist to mitigate these effects and, given the right scenario, could be used successfully to recoup establishment costs early and improve productivity. Further, research into new varieties and rootstocks have resulted in more horticulturally manageable cultivars that will, over time, replace the dominant Hass.

The report summarises current practices utilised to successfully manage high density plantings and presents a simplified management model. It concludes that while intensive production may not suit all regions and all management capabilities, it has the potential to increase productivity and could be used to counter the effects of lower returns in the face of over production.

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Foreword

My passion for the avocado started with a promise to never deal with another avocado again after a seven-year MSc program at the University of Natal, Pietermaritzburg, South Africa. In an ironic twist of fate, after a five year hiatus, it was the avocado that opened the doors of opportunity for immigration to Australia. Four years of consulting to the avocado industry in Western Australia had barely prepared me for a challenging opportunity in the beautiful Pemberton region in the south-west of the state when I crossed the line from giving advice to implementing advice. The challenge of farming, such a frustration as a consultant, was now a reality as I began to attempt to turn around a declining orchard.

The journey since 2009 has been a cliched tale of two step forwards, one step back as I tried to implement new technologies in the growing of avocados in consultation with one of the world's finest and well-known consultants, Tony Whiley. His insights and knowledge came to life delivered on farm instead of from the papers assigned for us to read at university when no context was present. In spite of this great resource, I still don't think I managed to grasp Tony's vision in all aspects of orchard management due to the great information asymmetry between us – he had seen the future of avocado management from his travels around the world and engagement with the top researchers and producers whereas my vision was limited to my theoretical knowledge and brief engagement with growing.

As this realisation became clearer, a seed that was planted during a conversation in my first year of Australian life with Steve Dilley, a 2002 Nuffield Scholar, began to grow. Nurtured by fellow Scholars and Zimbabweans Wade (2015) and Nicky (2014) Mann and encouraged by Tony Whiley, I decided to apply for a Nuffield Scholarship to see, explore and be a part of creating the future avocado industry. It was far more than I ever imagined it to be and while the asymmetry between my vision and Tony's will never be on a par, I believe that the experiences gained over this last year have changed the way I perceive an avocado, the way in which it is grown and the world that so enjoys it's amazing attributes.

Acknowledgments

'*A life spent making mistakes is not only more honourable, but more useful than a life spent doing nothing*' - George Bernard Shaw

While honour and usefulness are still being debated, a series of unfortunate events over a lifetime has surely prodded and pushed me to where I found myself applying for and being offered a Nuffield Scholarship. Were it not for the loss of my dad, the collapse of a country I called home, the fallout of a failed business attempt as an immigrant in the UK or the insatiable desire to farm, I wouldn't have heard of the Nuffield program let alone been in a position to accept a place. Looking back, I can see a life spent in preparation for a journey, unplanned at the time, to a destination that is still unknown.

For the opportunity that I find myself enjoying presently I must thank and acknowledge several people without whose influence and support I would be found wanting.

Firstly, to my dad whose company I enjoyed for only my first 24 years but whose spirit and character has kept me inspired ever since.

To the Avonova family and Tony Whiley who took me on with little experience, backed my decisions and allowed me to take so much time off work during one of our busiest years. To Phil, my farm manager and go-to guy for taking on so much of the development oversight and orchard management tasks while I was gone.

During my travels there were so many people that helped organise and connect me to avocado insiders beginning with Mary Lu Arpaia and Zelda van Rooyen who kindly included me as a late entrant, and completely unqualified, to the Avocado Brainstorming event in South Africa at which I was able to meet almost all of my personal travel contacts. Also, a great thank you to my Chilean acquaintances, Gustavo Cardemil, Francisco Mena and Juan Ortuzar who organized my Chile itinerary. My thanks must also go to Tim Spann for contacts throughout California.

Finally I would like to thank my wife, Kerry, and our kids, Hannah and Micah, who have endured a year of interruptions and absences – it has been a whirlwind schedule and the only way I have kept it together is through your support and understanding, thank you so much.

Abbreviations

AVIP	Avocado Variety Improvement Program
HD	High Density
LAI	Leaf Area Index
OHS	Occupational Health and Safety
PC	*Phytopthora cinnamomi*
PGR	Plant Growth Regulator
PBZ	Paclobutrazole
SIP	Strategic Investment Plan
TRV	Tree Row Volume
UCR	University of California, Riverside
UHD	Ultra-High Density

Objectives

- Outline key principles for high density production.
- Present a global perspective of high-density production systems and methods.
- Discuss the extrinsic factors affecting the success of high-density systems.
- Summarise the intrinsic orchard management practices that can be used to manipulate growth.
- Present an integrated diagrammatic model for high density production.

Chapter 1: Introduction

The avocado (*Persea americana Mill*.) is widely believed to have originated in the meso-American tropics between the latitudes of 23.5°N and 23.5°S in what is now known as Mexico and Guatemala (Schaffer, et al., 2013). It was a fruit that was favoured by the megafauna of the time presumably because of its high energy and nutrient rich pulp. This attraction was not lost on the early human inhabitants who followed the megafauna and, in time, became their replacements in the dissemination of the seed (Bost et al., 2013). The earliest archaeological evidence of human use of avocado comes from cotyledons found in caves in the Tehucan Valley in Mexico which date back to 7000 – 8000BC. The first western reports of avocado started to appear in the 16th century when Spanish explorers described a fruit whose flesh '*is like butter and is of marvellous flavour, so good and pleasing to the palate that it is a marvellous thing*' and '*the colour and shape is that of true pears, and the rind somewhat thicker, but softer and in the center of the fruit is a seed like a peeled chestnut, and in between this and the rind is the part which is eaten, which is abundant, and is a paste very similar to butter and very good eating and of good taste'* (Bost, et al., 2013).

The ensuing four hundred years saw the avocado spread around the world along the trading routes of the early merchants although its common consumption was largely confined to Latin America. The commercialisation of the avocado and the formal establishment of an industry began in Florida with the selection and vegetative propagation of superior seedlings in the early 20th century (Bost, et al., 2013). However, it was in the subtropical Mediterranean climate of California where the first globally commercially important varieties were selected and grown. It was here that the Hass variety was discovered as a chance seedling around 1926. By the early 1980s, Hass had become the dominant variety globally and today represents 80% of the world market (Handwerk, 2017).

The Australian avocado industry is relatively small, accounting for only 2% of the world's supply (Mulderij, 2018). Australian consumers, however, eat the most avocados per capita in the western world and it is this demand that has driven prices to record levels in recent years. The combination of strong marketing programs from the industry, some timely millennial woe commentary and the seemingly continual release of research confirming the amazing health benefits of avocados has resulted in a consistent 6% year on year demand growth over the last ten years (Avocados Australia, 2017). The high retail and farm gate prices have encouraged existing producers to increase their production and new entrants to establish new orchards.

The resulting predicted supply and demand trends are shown in Figure 1. The divergence of supply from consumption creates a number of issues for the producer. Most importantly it suggests that at some stage in the near future, supply will outstrip demand to such an extent that prices will drop. The industry's Strategic Investment Plan for 2017 – 2021 makes this very clear in its description of the major challenges for the sector and all four of the plan's outcomes addresses either the supply side or the consumption side of this conundrum. Particularly important from a production side is how the grower can increase productivity using the same amount of resources.

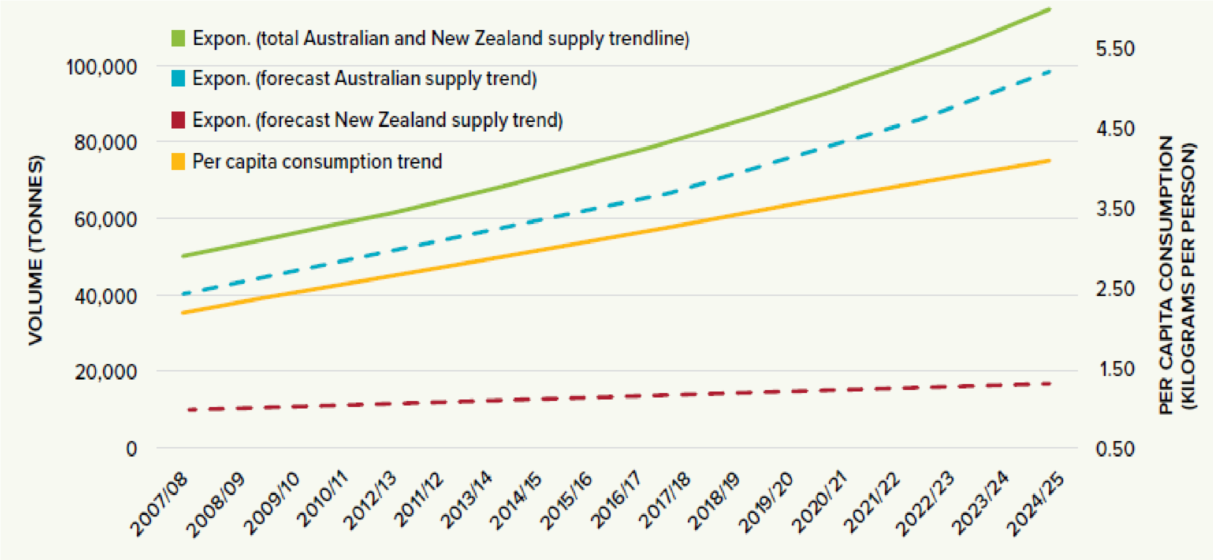


Figure 1. Supply vs Consumption Trends (Avocados Australia, 2017)

The six-year average yield for Australian avocado producers is 10.4t ha^{-1} (Avocados Australia, 2018). This compares to average global production which ranges between 8t ha^{-1} and 12t ha^{-1} (Wolstenholme, 1987; Wolstenholme & Whiley, 1995; Lovatt, *et al.*, 2015). The relatively low yield of avocado compared to other major fruit species is due to the complex and interdependent relationship between the evolutionary adaptive strategies of the species with a bias towards vegetative growth, the high energy cost of the fruit, being an oil crop with a large seed, environmental constraints on physiological processes and disease pressure (Wolstenholme, 1987; Wolstenholme and Whiley, 1995). Wolstenholme (1987) calculated the yield of avocado based on the crop's energy budget in comparison with apples and came up with a theoretical yield of 30t/ha. However, in the thirty years since this paper, producers have struggled to achieve even half of this target on a regular basis. It is interesting to note that relatively soon after Wolstenholme began this commentary, he and Whiley (1992) suggested that the most effective way of maximising early yields was through the establishment of high density plantings. Köhne & Kremer-Köhne (1991) published data indicating that high density plantings (800 trees/ha) had the potential to provide financial advantages over conventional plantings through precocity and accumulated yield per hectare. In spite of the conversation, and the apparent benefits of high-density orchard design, mainstream production has remained at conventional populations, seemingly discouraged by the absence of dwarfing rootstocks and low-cost management tools. This reticence to adopt new technology is still apparent today globally but is more stark in Australia where the average planting density sits at 219 trees/ha (Avocados Australia, 2018). By contrast, the Chilean avocado industry has embraced high density plantings with standard populations around 1,000 trees/ha and experimental populations of up to 6,000 trees/ha. However, it is interesting to note that the evolution towards high density production in Chile was not a direct result of a decision to improve productivity. Rather it was a result of the peculiarities of farming avocados in Chile where cultivation takes place on the steep slopes of mountains to avoid freezes lower down in the valleys. On these steep slopes, harvesting is a difficult and dangerous exercise. Smaller trees were seen as being beneficial and smaller trees meant more could be planted on a certain area which then gave rise to the interest in improving productivity through the use of certain practices that managed growth.

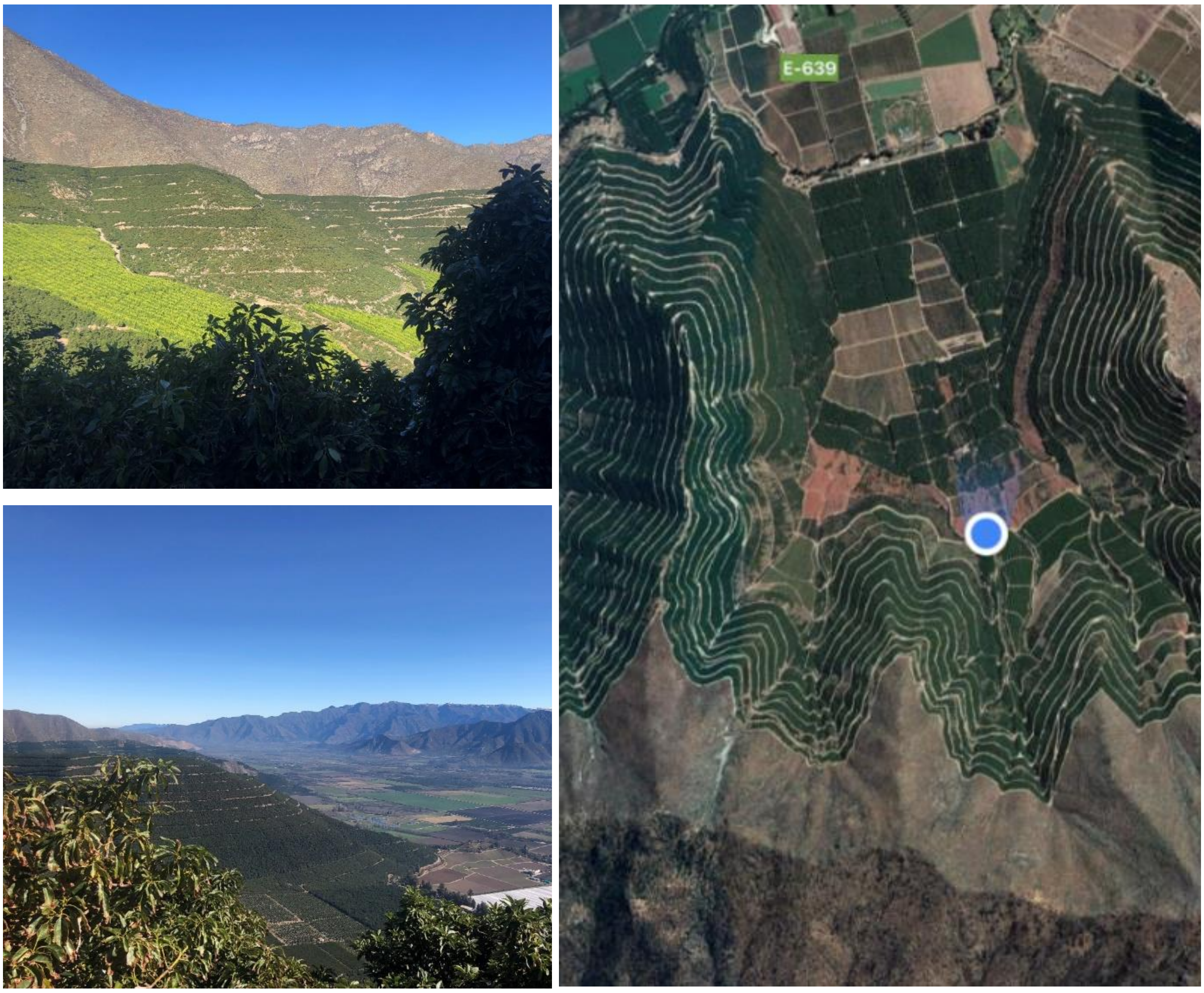


Figure 2. Avocado production in Chile on steep slopes (author)

Australian producers are facing similar pressures albeit from regulatory and finite resource origins as opposed to physical geographical constraints. Farmers in all industries across Australia are required to operate under increasingly strict Occupational Health and Safety (OHS) regimes. The harvesting of avocados from trees as high as 10m requires workers to operate elevated picking platforms. Regulators are concerned that the operation of these machines by unskilled labour is hazardous and are scrutinizing safety systems. As a result, harvesting using this type of machinery is becoming more expensive and burdensome. In addition to this regulatory pressure, finite resources such as suitable land and water are forcing farmers to look at ways to increase their productivity per unit of resource. These factors, in combination with the forecasted supply and demand issues (Figure 1), make it imperative for farmers to look at ways of producing more efficiently.

It is the aim of this report to investigate high density plantings around the world and to create a framework for an integrated management model for the Australian industry, taking into consideration the constraints on local production by ways of physical resource availability, costs of production and the burden of regulation.

Chapter 2: The Keys to High Density Planting

2.1 Light

High density systems are adopted for a number of reasons, the main being improvement of precocity and early yields, improvement of fruit quality and reduction of production costs (Palmer, 2004), all of which lead to an increase in return per unit land area.

There are two fundamental systems that play key roles in the success of high density orchards. These systems are light, its interception and distribution (Palmer, 2004), and the tree itself, its structure and ability to convert light into dry matter. The two systems are not mutually exclusive and indeed, the first system, although independent and non-controllable in its source, is wholly dependent on the second.

Light is a resource that is largely taken for granted in most agricultural systems, but it is the most important factor in plant production. Through the process of photosynthesis, light energy is converted into stored energy (biomass) in the form of vegetative and reproductive structures. The efficient capture and conversion of light is integral to high yields. The capture of light can be defined by two key concepts (Palmer, 2004):

- Light interception, and
- Light distribution

Monteith (1977) demonstrated a fundamental correlation between crop dry matter production and seasonal accumulated light interception. While there have been few avocado studies on this matter, a number of studies in apple orchards (Lakso, 1994) have shown that there is a close positive relationship between total seasonal light interception and fruit yield (Figure 3).

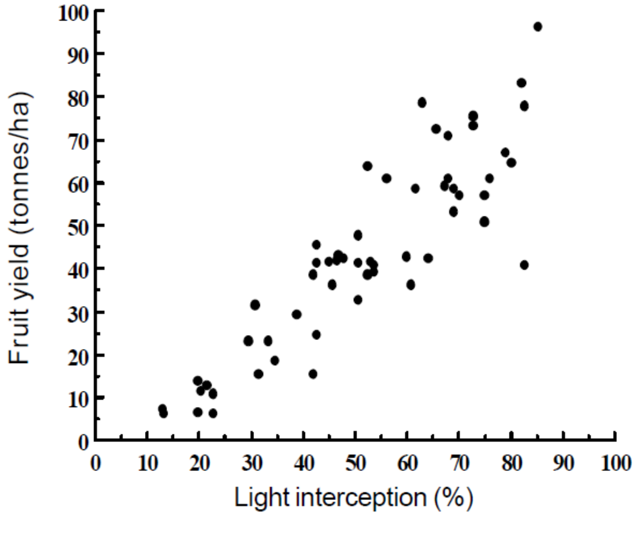


Figure 3. The relationship of total seasonal light interception to fruit yield in apple systems (Lakso, 1994).

Light interception is a function of a number of factors which are depicted in Figure 4 below.

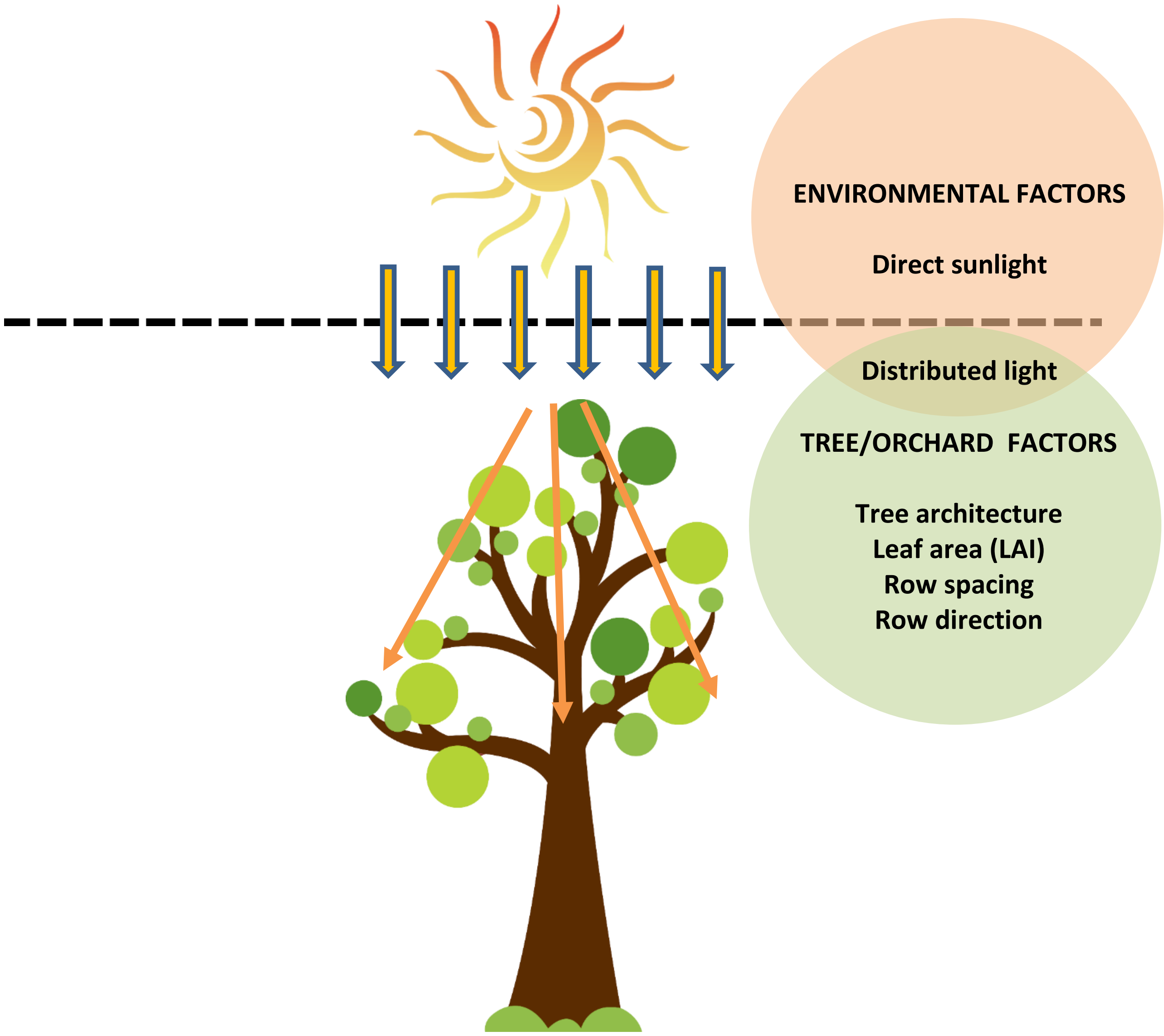


Figure 4. Factors determining orchard light interception (adapted from Palmer, 2004)

Potential light interception firstly is determined by the amount of light – the more light there is, the higher the proportional amount that can be intercepted. Distributed light is the light that is transmitted through the canopy and as such is a function of tree and orchard factors. Of these factors, tree architecture, leaf area index, row spacing and row direction are the most important (Palmer, 2004).

Tree architecture has been a major determining factor in the intensification of orchard crops. The ability to use dwarfing rootstocks and upright scions has helped the apple industry increase planting density. As between-row and within-row spacings decrease (densities *increase*), light interception improves (Wunsche & Lakso, 2000; Palmer, 2004). Smaller, more upright trees enable this intensification.

Leaf area index (LAI) is a measure of the total leaf area divided by the unit area that the canopy covers. It is used as an indication of photosynthetic production. However, LAI has an inverse exponential relationship with light interception such that at high LAIs, light interception plateaus (Figure 5a). In addition, as planting densities increase, the leaf area per plant decreases for a fixed LAI (Figure 5b).

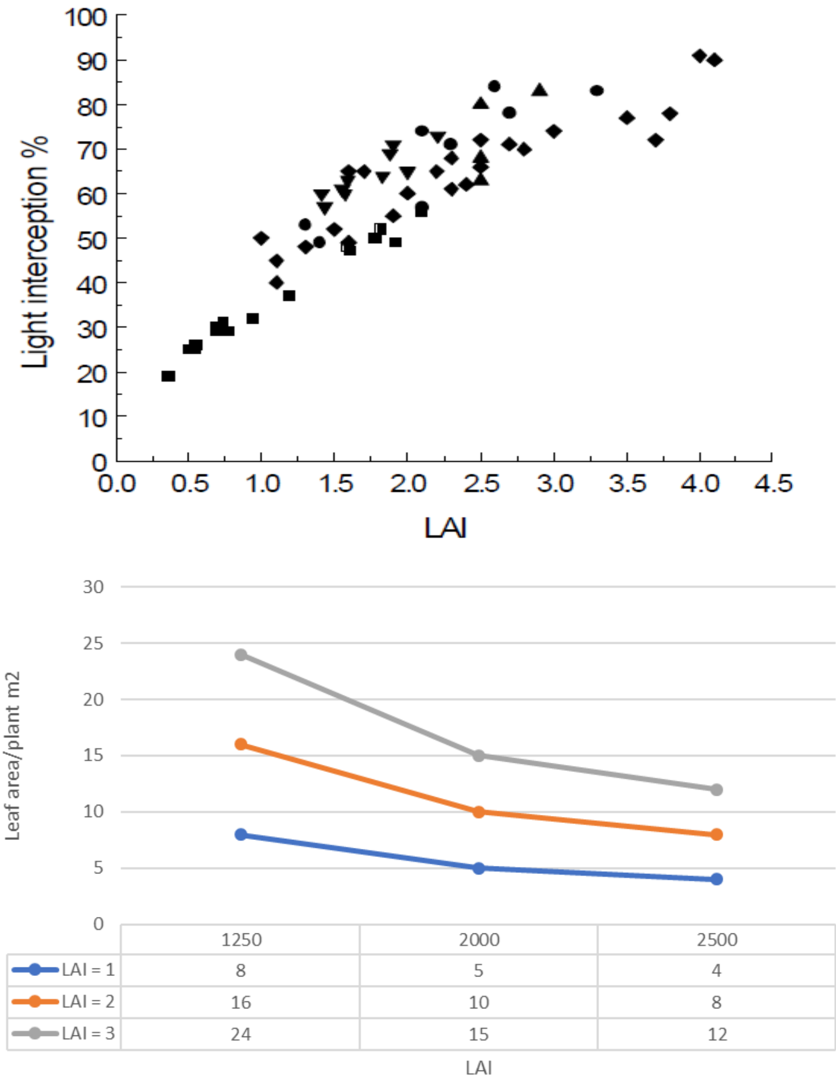


Figure 5: The relationship between LAI and light interception (above) (Lakso, 1994), and the inverse relationship between planting density and leaf area per plant (below) (Palmer, 2004).

In a four-year study of apple orchards in Australia, Middleton (2007) concluded that the most productive orchards had LAIs of between two and three. Productivity declined as LAI fell below 1.5 due to the trees not having enough canopy volume for high light interception. Further, Middleton (2007) showed that yields increased as light interception increased from 55 to 62% but that the majority of orchards surveyed intercepted less than this due to inadequate Tree Row Volume (TRV) as a result of being planted too far apart within rows and inter-rows being wider than necessary (i.e. planting density was not high enough). In the same study, tree height as a parameter of architecture, was found to be of less importance than LAI and planting density, and that as trees grew beyond one times the inter-row width, no substantial increase in light interception was observed while detrimental shading effects were exacerbated.

Light distribution through the canopy is the second concept determining light capture. Light distribution is important for a number of reasons. In many orchard crops, light penetration is important for the development of quality characteristics such as fruit colour, weight, soluble solids concentration and bitter pit incidence in apples (Palmer, 2004). It is also linked with flower bud development (Palmer, 2004), dormancy, shoot growth and leaf morphology (Bastias & Corelli-Grappadelli, 2012) in addition to its role in assimilation. Shading within the canopy has direct detrimental effects on assimilation when shaded leaves become sinks for energy due to a negative net photosynthetic rate and are effectively parasitic (Hadari, 2004). In avocado, Hadari (2004) showed that maximum light penetration through a healthy canopy was 1m, suggesting that canopy management should aim at restricting the thickness of the foliage.

In order to attain good light distribution through the tree, the tree's growth needs to be managed in such a way that a balance is reached between the need to fill the space and maximise interception, and the need to create an architecture that allows good light penetration.

How to achieve and maintain this balance is the purpose of this investigation and the following chapter describes the various approaches individual industries around the world have taken to try and achieve this.

In summary, the keys to successful high-density plantings are based on:

- Maximising light interception (60%) through
    - High density plantings
    - Management of LAI to between two and three – too high will result in excessive shading, too low will result in low interception
- Maximising light distribution through
    - Management of tree architecture and growth

Chapter 3: A Global Snapshot

3.1 South Africa

South Africa has a fairly long history of research into high density production systems (Kohne & Kremer-Kohne, 1990; Stassen, *et al.*, 1995) but little uptake in the form of commercial plantings. It would seem that the drivers for change have not yet reached their critical mass and any innovation in this area is from a purely academic viewpoint. However, two companies now hold key elements to the production puzzle and are carrying out interesting research that may change the way growers think about high density systems.

The first is Allesbeste Nursery, owned by Andre Ernst. Allesbeste Nursery selected and patented a Hass-like variety of avocado known as Maluma©.

Figure 6. Maluma© avocado

Maluma© is interesting from a high-density point of view because of its upright architecture. Allesbeste (The Maluma Blog, 2018) describe the canopy shape as upright, triangular with a central leader and lateral branching (Figure 7). The canopy density is open allowing good light penetration. Vigour is described as 'thrifty' and it supposedly has high precocity (Ernst, *pers. comm.*, 2018; The Maluma Blog, 2018). These characteristics make it an ideal fit for high density production.

Figure 7. Maluma©architecture showing dominant central leader and pyramidal shape (author)

To emphasize this feature, Zander Ernst has established semi-commercial trials on trellis systems designed to investigate how far the cultivar can be manipulated. Two trellising systems have been used at two different densities:

- **Tatura trellis** 800 trees/ha
- **Tatura trellis** 1250 trees/ha
- **Vertical trellis** 800 trees/ha
- **Vertical trellis** 1250 trees/ha

Figure 8. Tatura (L) and vertical trellis (R) systems for Maluma avocado (author)

Results have been collected for two years and show highly significant yield advantages over the controls (Figure 9).

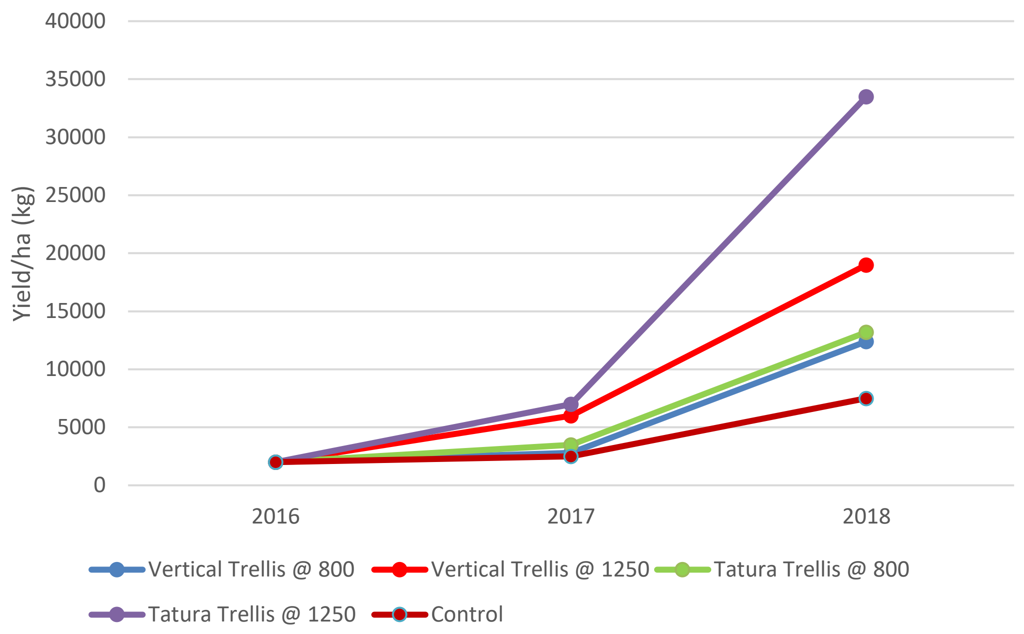


Figure 9. Yield data from trellis trials at Allesbeste Nursery (Ernst, 2018)

The early potential of these systems, utilising this variety, has been clearly demonstrated. However, it would be interesting to see if trellising would give any similar results utilising Hass. While there has been no investigation into the physiology behind the increases in yield using trellises, an argument for a role of increased light distribution through the canopy could be put forward. The considerably higher yield on the Tatura trellis could be due to a higher percentage of intercepted light.

The second company, Westfalia Technological Services, own the rights for marketing another variety called GEM. GEM is owned by the University of California but Westfalia have been trialling it since 1995 and have commercialised its production ahead of California. GEM, like Maluma, has characteristics that lend it to high density production. The tree's structure is upright but it has significantly less vigour than Hass resulting in a small, triangular shaped tree. The branches display a weeping habit, covering the fruit on the inside of the canopy and preventing sunburn. While Westfalia have encouraged the planting of GEM for their own supply chain, there has been little research done in South Africa on high density GEM plantings despite it being well suited.

In summary:

- The South African industry is based largely on conventional spacings
- Drivers for change are largely absent although a few forward-thinking growers are experimenting
- New varieties, better suited to high density plantings, are accessible

- Tools for growth control such as paclobutrazole (PBZ) and uniconazole are available but are not widely used
- Pruning is not a focus of many orchards although some growers do use mechanical pruning techniques

3.2 California

California is the birthplace of modern commercial avocado production. The University of California possesses the largest germplasm bank in the world and most of the modern varieties were selected in California. In spite of the rich history of avocado culture in California, the industry itself faces multiple challenges. Water quality and availability are declining, land prices are exorbitant, and labour is becoming problematic from a cost and regulatory standpoint. In addition, international competition from Mexico, Peru and Chile require local growers to improve their productivity. These factors have encouraged innovation and discussion, but widespread adoption is still low albeit higher than in South Africa and Australia. This slow uptake is due to a number of reasons, some of which are common throughout the global avocado industry. The most obvious is an entrenched view, reinforced over decades, that avocados have a long productive crop cycle of up to 30 years. Whilst this is not untrue, the existence of such a belief has slowed down advances in productivity gains that are apparent in other fruit crops where orchard turnover is encouraged at shorter intervals. One of the drivers of change in other, older industries is the breeding and release of new and better rootstocks and varieties. The existence of superior cultivars with better taste, more disease resistance and grower friendly attributes gives impetus to change. This is a key element that is lacking in the avocado industry. Dwarfing rootstocks and scions with phenotypical attributes that suit high density plantings are not readily available. However, there is potential in the germplasm collection that the University of California Riverside (UCR) holds (Figure 10) and a new initiative called the Avocado Variety Improvement Program (AVIP), a collaboration between UCR and private investors, aims to advance the existing UCR program as the world's premiere source of new varieties. This new, well-funded, impetus will undoubtedly produce results in the future, and give growers additional motivation to start looking at orchard turnover solutions and high-density options.

Of particular interest for high-density production are the semi dwarfing rootstock P35 (still in trial phase) and the previously mentioned GEM scion variety. GEM is becoming a more popular variety in California due to commercial evidence for its precocity, high consistent yields and smaller stature (Figure 11). Growers are more confident in its ability to perform in high density orchards, and also in its resilience to extreme weather events. Rob Brokaw (*pers. comm.*, 2018) of Brokaw Nursery, the largest avocado nursery in California, cited that 20% of the orders for trees are now GEM and most of the plantings are going in at densities above traditional spacings (Figure 12).

Figure 10. Different scion phenotypes at the germplasm block at UCR (author)

Figure 11. Six-year old GEM planted at 5m x 2m (1000 trees/ha) with a heavy set at Brokaw Nursery's production block, Ventura, California (author)

Figure 12. High density plantings of GEM in Ventura county, California. Left, 5m x 2m planting of GEM avocado at Dominguez Ranchos. Right, 3m x 3m planting of GEM avocado at Brokaw Nursery (author)

New rootstock and scion varieties are one tool in the grower's toolbox, but development times are prolonged and market acceptance is not guaranteed. Growers need to be able to manage current plantings with current varieties. California is unique in that the plant growth regulators (PGRs) commonly used in other production regions around the world, uniconazole and paclobutrazol, are not available for use. Producers therefore must rely on physical control of growth through girdling and selective pruning.

Girdling is the process of interrupting phloem transport by cutting through the cambium layers around a branch (Figure 13). It results in the accumulation of carbohydrates above the cut and is used to promote flowering and fruit set in vegetative branches and as a growth control mechanism in Hass orchards.

Figure 13. Girdling (or cincturing) of avocado (author)

Growers in California use girdling to promote flowering in vigorous, upright vegetative branches commonly called water shoots. These shoots are common in Hass after pruning and if left alone, will grow vertically without setting fruit and end up shading other areas of the tree. Girdling is typically carried out on one or two-year old wood which, after setting fruit and being harvested are removed through pruning. If girdled branches are left on the tree, there is anecdotal evidence that slow decline decreases production of that branch even though the wound heals. There are, however, drawbacks to this method. It is labour intensive and management intensive since knowledge of what branch and where on the branch to girdle is required. There is also evidence that girdling weakens branches and makes them more prone to snapping off during wind events. Nevertheless, it is an important management tool in the absence of PGRs.

More widely adopted among high density proponents in California is a disciplined pruning program. While the act of pruning is adhered to strictly every year, the *method* of pruning is more loosely defined. In general, growers operate under a rule of thumb based on the height of the branch to be removed. It states that if the branch is at knee height the cut is to be made

50cm from the trunk; if the branch is at waist height it is to be cut 25cm from the trunk; if the branch is above shoulder height it is to be cut off at the trunk. This creates a triangular tree shape over time. However, pruning decisions are not always as clear cut as the rule of thumb would have it and once again management time is critical in the choice of *what* to cut. Timing of pruning is also critical. Generally. most of the growers commence their pruning programs directly after harvest. This allows regrowth from dormant buds to reach a suitable size for girdling in the late autumn on early pruned branches and possible flowering in the spring of the same year. Pruned limbs therefore have a two-year cycle from harvest to harvest.

In summary:

- The Californian industry is in the midst of change as new plantings are tending towards higher density production
- Drivers for change are strong
- Adoption of horticulturally better suited varieties is gaining momentum
- Physical manipulation of growth through pruning and girdling is widely used
- The absence of chemical control with PBZ and uniconazole makes growth management expensive

3.3 Chile

The Chilean industry is unique in its use of hillslopes with steep inclines for the cultivation of avocados (Figure 14). The shallow soils and cool Mediterranean climatic conditions of these aspects are not conducive to excessive growth (Whiley, et al., 2013) while the steep slopes and inaccessibility to machinery dictate that trees are kept small for ease and safety of harvest. These conditions have led to the intensification of plantings and the rise of ultra-high density production systems of up to 6,000 trees/ha (1.25m x 1.25m spacings). While there are large areas planted to these ultra-high density systems, the majority of plantings range between 800 and 1,600 trees/ha which is still significantly higher than the majority of production systems globally.

Figure 14. Chilean avocado production in the Quilotta region. Avocados on steep slopes (left), and land preparation for planting avocados (right) (author)

The Chilean industry has several factors that work in its favour which allow for such intensification besides the aforementioned climatic and soil characteristics.

- *Phytophthora* root rot pressure is minimal due to the low rainfall which has allowed widespread use of seedling rootstocks which are far cheaper than clonal rootstocks thereby reducing capital costs.
- Labour is cheaper – although availability is becoming a problem.
- Regulation of PGRs has allowed both soil and foliar applied methods for some time
- Human capital – Chile is particularly distinct from other national industries in that reservoirs of knowledge servicing the avocado industry are abundant and willing to cooperate and collaborate – a national advantage that gives it a competitive edge.

Management of tree growth in Chile focusses on three different areas:

- Chemical control.
- Physical control.
- Management of tree health.

The basis for successful high-density production is a healthy tree. Much attention is given to irrigation practices with most orchards operating on a times evapotranspiration (ET_o) factor and irrigation scheduling every 2 – 3 days due to the heavy soils. Drip and micro-sprinkler systems are both used although research by Gama, a consultancy group, suggested that micro-sprinklers gave 20% more yield (Mena, *pers. comm.*, 2018). Drip irrigation was, however, always used in the first year of production in order to deliver water and nutrition directly to the newly planted tree root system.

In high density plantations, the aim in the first year after planting is to grow the tree to a stature which could support flowering and fruit set through to harvest in the second year. The yield target in this second year is 10t p/ha in densities of 1,600 trees/ha (2.5mx 2.5m). This precocity is encouraged through the use of uniconazole, firstly as a foliar spray in the autumn of the first year to encourage flower induction and bud development and then at flowering to help fruit set. In some scenarios where the tree is very vigorous, girdling may be used but this is not a management practice that is used by all growers.

Subsequent canopy management practices in older orchards utilise judicious use of girdling, bi-annual pruning and two to three applications of uniconazole as a foliar spray and/or soil drench through the irrigation.

3.3.1 Girdling

Girdling is not a practice that is used by all growers in Chile. However, Agricom, the third largest exporter of avocados in Chile uses it extensively, probably as a part substitute for a reduced chemical program. Successful, repeated girdling relies heavily on the trees being in good health and, as seen in Figure 15, multiple girdles can be made as long as the limb remains vigorous. In most cases, girdled branches are removed after harvest as part of the canopy management program. Occasionally, if management decides that the height or complexity of the tree falls within acceptable limits, girdled branches are left for another year as seen in Figures 15b-c. Girdling is not without its problems. As mentioned in chapter 2.2, girdling is labour intensive and relies on semi-skilled workers making subjective decisions that can affect orchard performance and due to this risk, Agricom was the only grower that was seen to be utilizing this technique.

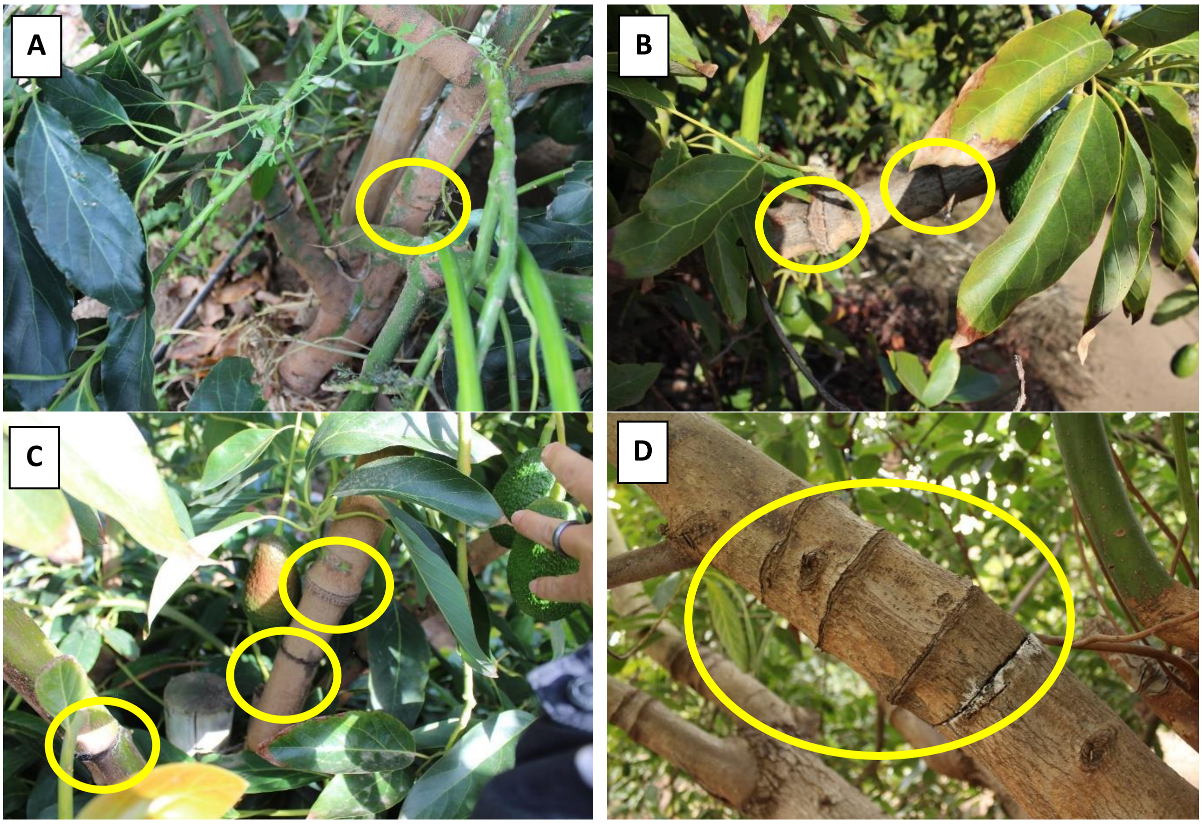


Figure 15. Girdling. (A) Girdling on young branches to encourage flowering and fruit set. (B) Multiple girdles in subsequent years on lateral branch. (C) Multiple girdles in upright branches on a multi-leader young tree. (D) This vertical leader has been girdled four times suggesting a four to five-year old limb. Normally this should have been pruned out

3.3.2 Pruning

There are various pruning philosophies being adhered to in Chile. In contrast to the Californian simplified pruning triangle, one train of thought did not restrict pruning to a certain shape. Rather the aim of the pruning cut was to stimulate new growth and complexity. The reasoning behind this was that because of the continuous growth model of the avocado, bearing points were always on new growth. Therefore, old growth should be restricted to as small a volume of tree structure as possible – the stump – from which new growth was stimulated and coerced into bearing. After a certain height was reached or if the branch was creating access problems, it would be removed down to the stump again (Figure 16).

This type of pruning was not restraining in terms of the final shape of the tree – complexity and young wood was key. It was interesting to note that in the orchards that practiced this type of pruning, PGRs were only used at flowering to aid in fruit set and perhaps once more during the season to control vegetative flushing. Both applications were foliar.

Figure 16. 'Stump' pruning. These images clearly show the 'old' wood volume being minimised and 'new' bearing wood being stimulated to grow out (author)

The second pruning philosophy attempted to restrict the tree's height and with the aid of PGRs and the weight of set fruit, bend the ensuing growth down into a 'weeping' architecture. This method was developed by the Gama group and is used in the ultra-high density plantings of 1600 trees/ha. The tree is left to grow to a height of 1.8 – 2.2m, at which stage it is pruned. This typically happens immediately after harvesting. The buds that break following this cut are left until they are approximately 20cm long. Uniconazole is then applied through the irrigation at a rate of 4L/ha. The effect of uniconazole is the reduction in internode length and a 'bending' of the weaker shoots so that they actually grow laterally or slightly downward. The stronger shoots that grow up from the prune, referred to previously as water shoots, are not as affected and remain growing vertically. These are removed by a second pruning exercise in the winter. The subsequent spring flowering and fruit set on the laterally growing branches results in the increasing weight of the fruit pulling the branches into a weeping habit (Figure 17).

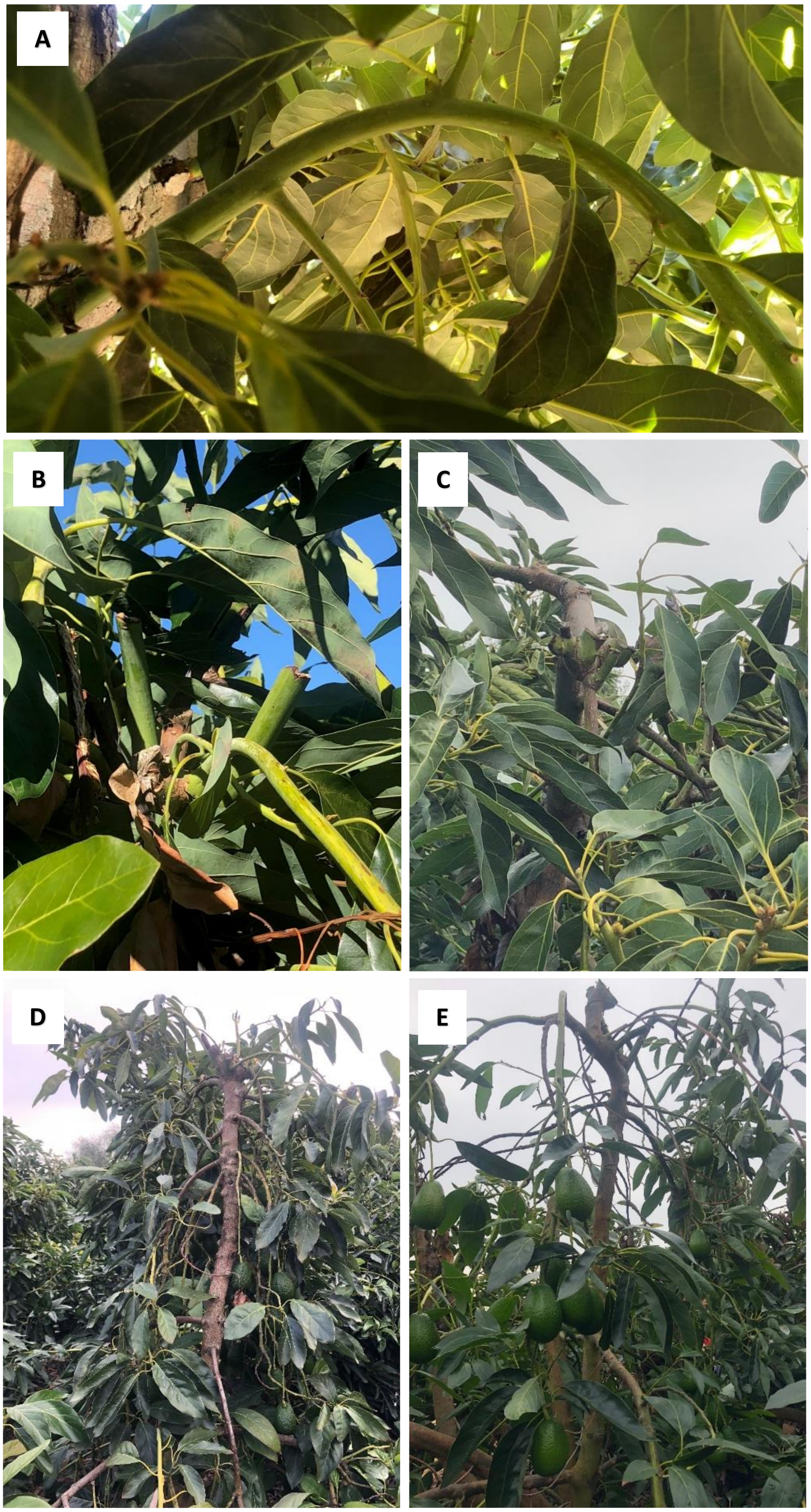


Figure 17. 'Weeping' pruning examples. (A) The effect of uniconazole on the weaker branches; (B) The removal of watershoots at the height of the prune (this particular example was not done quite right as stumps of the shoots should not have been left); (C) A

better example of pruning vigorous shoots at the assigned height; (D) A 'weeping' prune example. Note the columnar shape of the tree as opposed to a triangular shape; (E) Another whole tree example clearly showing the prune which has been cleared of vigorous shoots and the bearing 'weeping' laterals (author)

3.3.3 Plant Growth Regulators (PGRs)

The most commonly used PGR used in the Chilean industry is uniconazole or Sunny™. It is an anti-gibberellin and restricts cell elongation resulting in reduced internodal length. Since gibberellins are also involved in a number of other physiological processes such as flowering, uniconazole also has an effect on these. In particular, the application of uniconazole enhances the flowering intensity. It is used in a number of ways in avocados but primarily as a growth inhibitor. Timing of application is extremely important. Trials by various research groups in the early 1990s showed that application of the anti-gibberellin paclobutrazol at mid-bloom had positive effects on fruit set and fruit size (Wolstenholme, *et al.*, 1990; Whiley, *et al.*, 1991). Similar results are found when uniconazole is applied at flowering, when the spring flush is approximately 5 – 10cm long in 90% of the orchard. Whilst generally accepted as being effective, recent conversations with Harley Smith (CSIRO, *pers. Comm.*, 2018) and anecdotal evidence from Mena's group in Chile (*pers. Comm.,* 2018) suggest that later applications may be more useful. Indeed, the second application window which occurs when the spring flush is approximately 20cm long is used as the main opportunity for growth control. Application at this time is through the irrigation at 4L/ha. At this stage of growth, the transpiration stream is mainly being driven by the leaves of the new flush which are not quite fully expanded. As a result, chemical uptake through the roots accumulates in the new shoots and leaves where it is required. The phenotypical effects are fairly dramatic with tight, curled leaves and very short internodes (Figure 18).

Figure 18. Effects of uniconazole on the whole tree (left) and on internode length (right) (author)

PGRs are incredibly powerful tools for the management of tree vigour and in the absence of dwarfing rootstocks and scions, are absolutely necessary for high density production.

In summary:

- Chilean producers have been driven to change by geographical challenges although regulatory and resource scarcity are adding pressure
- High density plantings are the norm and ultra-high density orchards are not uncommon
- Hass is the dominant variety and although Maluma and GEM have been planted there is little momentum to change
- Management of tree growth is accomplished primarily through pruning and PGR application with some orchards using girdling

3.4 New Zealand

The New Zealand industry is undecided about the value of high-density production of avocados which is unusual for two reasons. Firstly, the New Zealand horticultural industry is highly innovative with the apple and kiwi fruit sectors routinely acknowledged as being world leaders. Secondly, pressure to improve productivity is high with skyrocketing land values and depleting water reserves. The demographics of the avocado industry might explain this apparent recalcitrance with many of the growers being of an older generation.

There are some exceptions, however, particularly in the north of the North Island where corporate interests have recruited some Chilean expertise. Not surprisingly, these orchards were being managed using a combination of PGRs and pruning techniques not dissimilar to the Chilean industry. The climate in this region was far more challenging than the semi-arid cool Mediterranean climate of central Chile, being a warm maritime subtropical climate inducing vigorous extension which was very hard to control even at elevated rates of PGR application. In spite of these challenges, the recent yield history was impressive, vindicating the choice to plant at high densities (Hermosilla, *pers. comm.*, 2018).

In summary:

- Little to no traction of high-density philosophy even though drivers for change are strong.
- Orchards that have planted high density struggle with excessive growth even with the ability to apply elevated rates of PGRs.

Chapter 4: Building the Model: Defining the Foundation Blocks

Intensification of production of avocados is the next step in the evolution of orchard management for this crop. Domestication is still a long way behind that of apples and citrus but by utilizing current knowledge and available technology, a reasonable outcome can be achieved. However, it must be noted that some circumstances are more desirable than others and that the overarching effects of climate and soil have great influence over management philosophy, such that high density production may not be possible or economically desirable. The following sections discuss the inherited attributes of a system – the unchangeable characteristics of climate and soil that underlie and shape management practices.

2.2 Bioclimatic region

The industries visited provide a continuum of bioclimatic examples from the cool Mediterranean climate of Chile through the warm Mediterranean conditions of California to the warm subtropical areas of Tzaneen, South Africa. Wolstenholme and Sheard (2012) usefully categorize conditions for growing avocados as being invigorating (warm, summer rainfall, subtropical areas) or non-invigorating (cool, arid winter rainfall areas) (Figure 19).

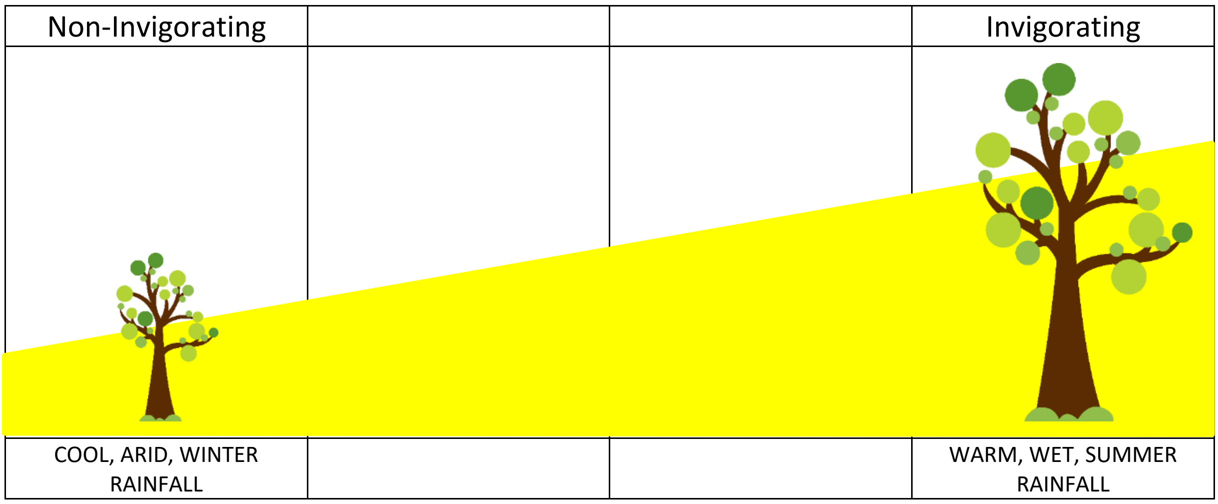
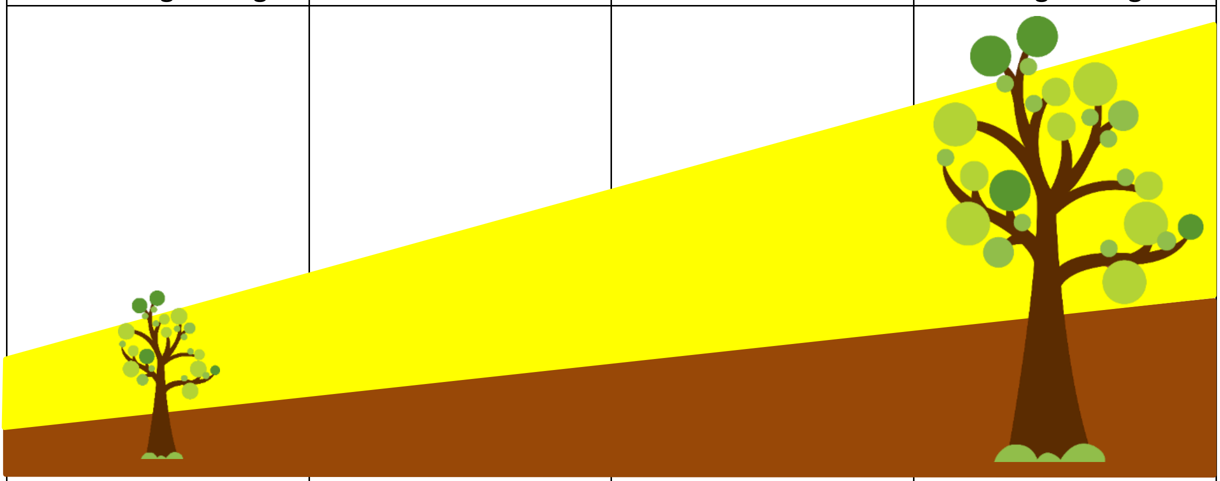


Figure 19. The continuum between non-invigorating and invigorating climatic groups (Wolstenholme and Sheard, 2012)

2.3 Soils

Likewise, soils can also be classed as invigorating or non-invigorating. Invigorating soils have excellent aeration and drainage, are deep, friable, fertile and have high organic matter content (Wolstenholme & Sheard, 2012). Such soils promote vigour. In contrast, soils that are shallow, high in clay, infertile and low in organic matter do not promote vigour. Soils with poor drainage promote conditions for *Phytophthora cinnamomi* (PC) to infect roots. A myriad of combinations of soils can be found within climatic groups and it would be difficult to illustrate all the scenarios within one model. For simplicity, the additive effect of soil on tree growth is shown in Figure 20.



Non-Invigorating			Invigorating
COOL, ARID, WINTER RAINFALL			WARM, WET, SUMMER RAINFALL
INFERTILE, LOW ORGANIC MATTER, POOR DRAINAGE, SHALLOW			FERTILE, HIGH ORGANIC MATTER, GOOD DRAINAGE, DEEP

Figure 20. Soil type overlaid on bioclimatic effects on tree vigour* (*Wolstenholme and Sheard, 2012)

It must be emphasized that with regard to soils, the characteristics of infertility, poor drainage and shallowness are not recommendations for growing avocados – choosing these soils as a preference would likely result in disaster. Rather, it is a depiction of a range of conditions that would affect tree growth and final size. For example, the soils in Chile would be regarded as poor in terms of drainage and clay content but because the climate is non-invigorating and rainfall is low and PC disease pressure is low, they are suitable for growing on. The same soils in the warm subtropical climate of Tzaneen in South Africa, with high summer rainfall, would result in crop failure.

Except in start-up projects where climate and soil can be selected to a certain degree, in existing projects they form part of the foundation on which all other decisions have to be made. Given a certain combination of soil and climate, the grower can gauge the suitability of the situation to intensification and begin to choose the tools available for that particular combination. These tools begin with the decision of cultivar and rootstock combination to utilize.

2.4 The tree

The tree is the central unit of production and its shape, form and ability to be controlled have to be considered. Unfortunately, in this regard, the confounding effects of market preference have an unduly large influence over choice although this may begin to change in the next crop cycle (15 -20 years) (Focht and Iturrieta, *pers. comm.*, 2018). In addition to this complexity, zonal microclimates have different effects on the characteristics of certain cultivars such that they do not perform in a similar way to where they were selected (cf. GEM in the cool south west of Western Australia). A test planting is therefore recommended before a decision is made.

4.1.1 Cultivar

Hass is the predominant variety and by far the most preferred in the market. Horticulturally, however, it has been described as a 'monster' (Focht and Iturrieta, *pers. comm.*, 2018) due to its unruly growth habit. It has been classified as being intermediate in terms of its vigour and somewhere in between the upright 'Reed' cultivar and the spreading 'Sharwil' cultivar in terms of its structure.

More recently, varieties such as GEM and Maluma have been selected with horticulturally 'friendly' attributes such as low vigour (semi-dwarfing) and more upright growth habits. Being Hass-like, it has been suggested (Brokaw, *pers. comm.*, 2018; Focht and Iturrieta, *pers. comm.*, 2018) that eventually these cultivars will dominate the market as more growers adopt them in preference to Hass. Change in consumer preference will be driven through changes in production practices rather than from a change in demand partiality. Much like the famously quoted Henry Ford adage "*if I had asked people what they wanted, they would have said faster horses*", avocado consumers will eat what the industry decides to produce.

One other cultivar worth mentioning is Reed. Reed is classified as being intermediate in vigour (Wolstenholme and Sheard, 2012) and upright. It is a heavy bearer and in an ultra-high density planting in California (2.25m x 2.25m), produced 80t/ha in the 6^{th} year of production (Hofshi, 1999). While not a mainstream variety, it is a recognised variety in the marketplace with significant advantageous attributes.

Cultivar selection plays a crucial role in management practices given that each variety will have a different response to the conditions and methods of growing. Building on the foundation model presented in the previous sections, cultivars can be classified as in Figure 21.

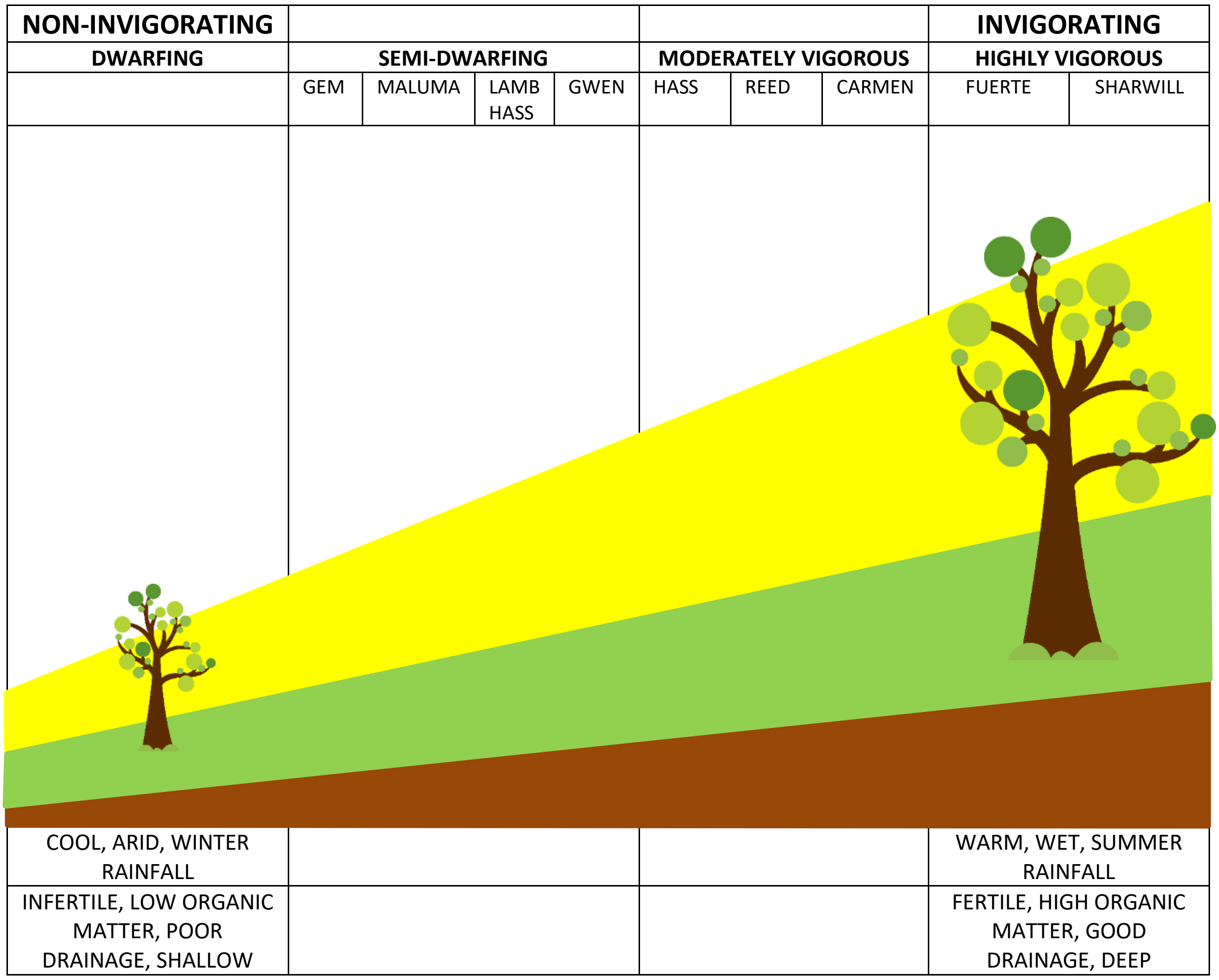


Figure 21. Cultivar classification **(*Wolstenholme & Sheard, 2012)***

4.1.2 Rootstock

There is no truly dwarfing rootstock nor is there a rootstock that is resistant to PC in avocados (Figure 22). In addition, those rootstocks that are tolerant of PC are generally vigorous – the mechanism of tolerance being the ability to 'outgrow' the fungus. These two omissions in the toolbox make rootstock selection a problem. The Chileans have opted for seedling rootstocks which decreases the cost but increases variability. The South Africans and Californians have established industries based on clonal rootstocks which gives better uniformity and disease tolerance but more establishment cost. Choice ultimately comes down to priorities – disease tolerance versus vigour, cost versus uniformity. Further, the current global shortage of trees (up to 6 years wait in South Africa), presents the grower with a limitation of choice and the unwanted predicament of having to choose between having trees in the ground with whatever material is available or waiting for the fulfilment of a desired order. There is enough anecdotal evidence to suggest that with good management practices for PC control, trees in the ground with whatever material is available is as good as high cost clonal trees even though the uniformity and tolerance of these rootstocks is preferable in the long run.

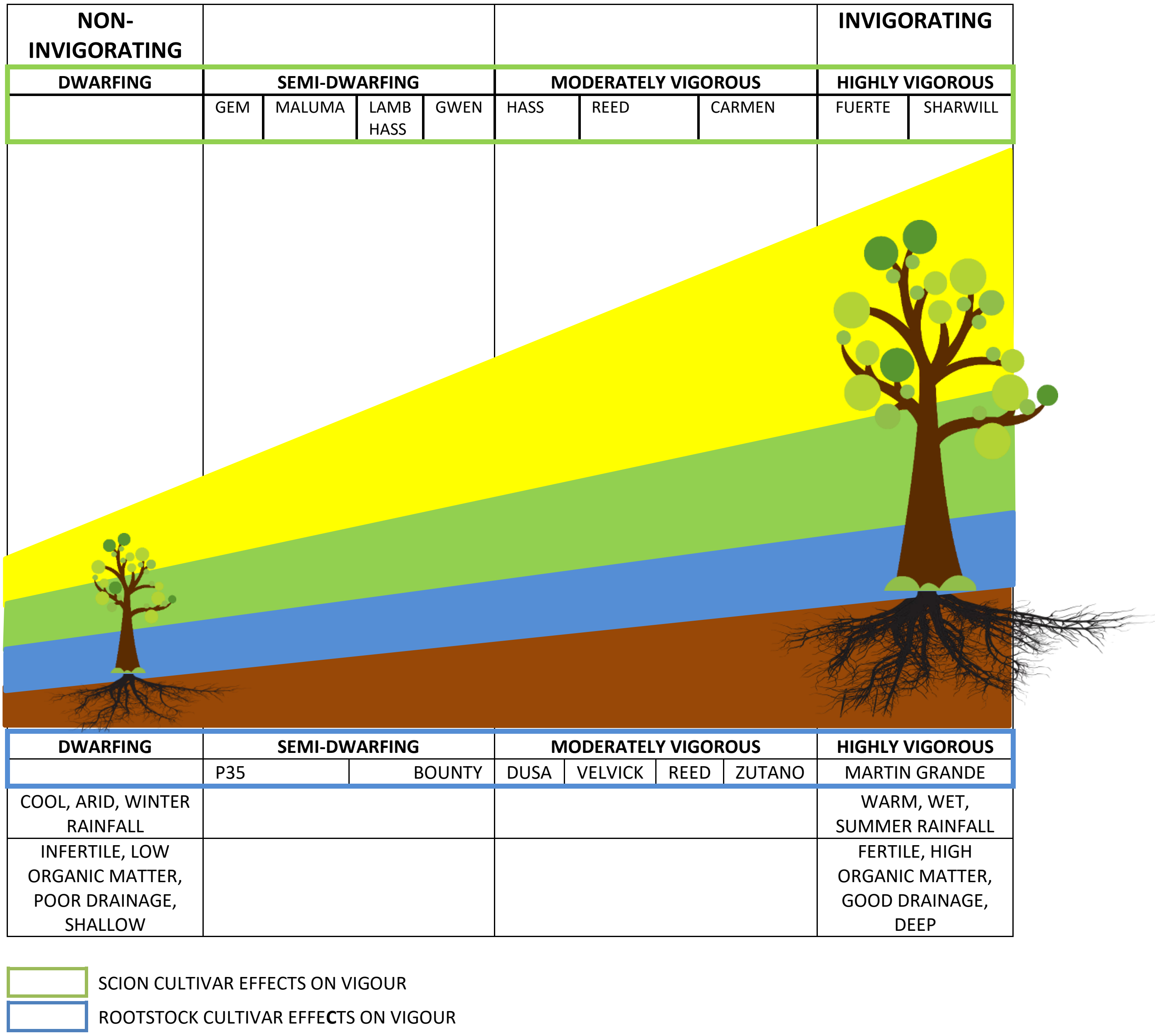


Figure 22. Rootstock effects on vigour (Wolstenholme & Sheard, 2012)

2.5 Orchard design

The final foundation block is orchard design. Wolstenholme and Sheard (2012) suggest a categorisation of densities – high density (HD) being between 500 and 1000 trees per hectare and ultra-high density (UHD) being more than 1000 trees per hectare. For the purposes of this report, these same categories will be used from hereon. There are physical limiting factors on density besides the effect of light that was discussed in Chapter 2 that are specific to various industries. These may include considerations such as the use of machinery inside the orchard, slope and the expense of earthworks to mitigate its effects as well as harvest systems. The Australian industry relies on machinery to reduce labour costs although harvesting, presently, is done by hand. Intensification of production requires that these factors are taken into consideration when designing the orchard. Figure 23 illustrates a working plan for Australian conditions with a serviceable inter-row of 3m.

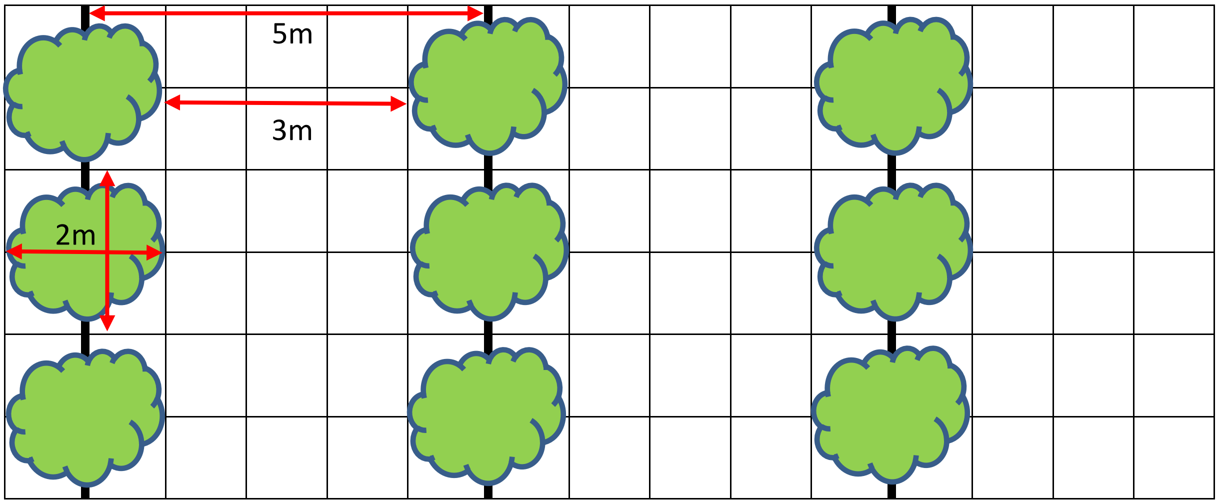


Figure 23. An example of orchard spacing under Australian conditions (author)

The design in Figure 23 takes into consideration several factors discussed in previous chapters. Starting with the required row width for machinery and allowing some versatility gives a figure of 3m. According to Hadari's (2004) thesis, light penetrates to a maximum of 1m suggesting a theoretical maximum tree diameter of 2m. Middleton (2007) suggests keeping the height of the tree to between 0.8 and 1.0 times the row space width in apples. In avocados, because of the denser canopy, it could be postulated that this be reduced further, and, in the case of producers wanting to move away from elevated work platforms for harvesting, even down to between 0.4 and 0.5 times the row width. However, this is untested and does come with an obvious reduction in Tree Row Volume and therefore potential bearing points.

Other designs can include access rows for machinery. This was observed at Ranchos Dominguez in Ventura, California where every fourth row there was a machinery access lane. However, in this particular orchard all spraying was done by hand.

Orientation of the orchard should be as far as possible North to South since the potential light interception in this alignment can be 15 – 20% higher (Middleton, 2007), although this factor should not come at the expense of good drainage and/or relief considerations.

The above sections have outlined several key factors to be considered before high density systems are implemented. It goes without saying that there could be any number of complications in the combinations and choices of these four elements due to regional and sub-regional idiosyncrasies in each of them. However, with a logical consideration of each foundation, management practices can be implemented to accentuate or minimise the effect. The following chapter presents these management tools and discusses different ways of using them.

Chapter 5: Building the Model: Adding in the Complexities

5.1 Early tree growth

The aim of HD planting is to promote precocity and recoup establishment costs through early commercial yields. In order to do this the tree must be grown to a suitable size in its first year in order to carry a crop through its second year. Palmer (2004) maintains that the orchard begins in the nursery and that in the early years, yield is a linear function of light interception which is determined by how quickly the tree fills its space. This, in turn, is governed by tree quality at planting. In HD apple production, nursery trees tend to be 'feathered' or complex. In contrast, the majority of avocado plants from nurseries tend to be single leaders. There is considerable debate about this discrepancy but if the argument is looked at logically and in light of evidence put forward in this paper, it would appear that in order to fulfil the growth requirements, trees should be complexed earlier than is the case currently. Based on Hadari's thesis (2004) it could be possible to select a leader for every meter between trees in the row so that a 2m spacing has two leaders and a 3m spacing has three and so on. This is based on the behaviour of light distribution through the canopy. As of yet this has not been tried.

Whether a single leader is maintained, or a tree is complexed, the objective in the first year is to grow the tree to fill its allotted space. This means that the management practices of irrigation and nutrition need to be optimised. Under non-invigorating conditions this may be a challenge to achieve due to sub-optimal growing conditions but under invigorating environments, vegetative growth may dominate to such an extent that flowering at the end of the first year is suppressed. This is not an ideal outcome and requires intervention in the form of PGR application to encourage flowering.

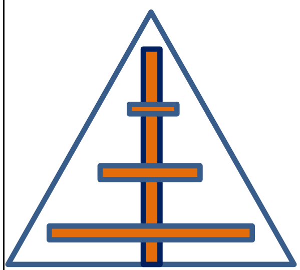
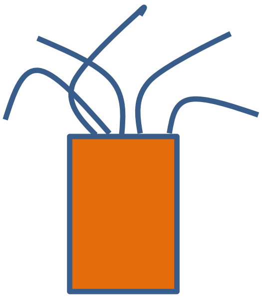
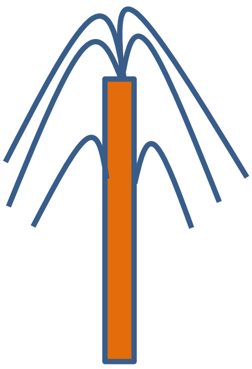
Complexing the plant can begin in the nursery or in the field post planting. However, it must be carried out with the end in mind – this being the ultimate shape of the tree and the pruning philosophy supporting it, which is dealt with in the following section.

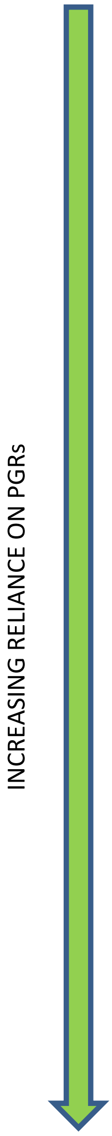
2.6 Controlling tree vigour

There is a paradox between the idea of pushing the tree to fill its allotted space (vegetative growth bias) and then controlling its size (vegetative:reproductive balance). This second challenge seems to be part science and part art, making management both complex and intense. The science involves the pruning system to be adopted and the application of PGRs. The art involves the decision of what to cut and when to cut, the balancing of current and future production and, the timing of PGR application.

5.1.1 Pruning systems

The pruning systems encountered in HD plantings are summarised in Table 1.

TYPE	METHOD
Triangular 	PHILOSOPHY: Selective removal of limbs to form a triangular shaped tree. Limbs are removed systematically with preference given to those obstructing access and those shading from the outside. In invigorating environments where there is a gap between harvest and next season's flowering, mechanical pruning could be used.
Stump 	PHILOSOPHY: Maintenance of 'old wood' to a minimum volume with all production based on young wood. Branches are removed systematically around the stump based on productivity. Tree shape is undefined. Girdling is often used to promote precocity.
Weeping 	PHILOSOPHY: Maintenance of height through continuous pruning and removal of watershoots from a central leader PGRs are used to 'bend' lateral growth into weeping shape.



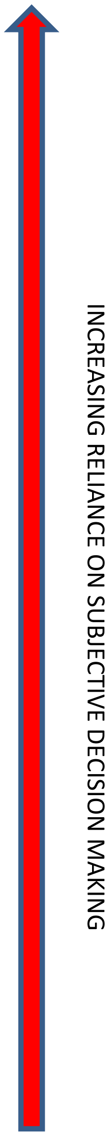


Table 1: Pruning Systems (author)

All the above pruning systems require two cuts – the first being the primary cut post-harvest, the second being a follow up to remove excessively vigorous growth normally carried out in winter. Each system has its advantages and disadvantages in terms of management intensity but can also be adapted somewhat to individual circumstances.

5.1.2 PGRs

As mentioned before, there are two PGRs utilized in avocado production – uniconazole and paclobutrazole. Both are anti-gibberellins and belong to the triazole group of compounds. It is not the aim of this report to go into the detail of the physiology of their mode of action, suffice to say that the effect of uniconazole is less persistent than that of paclobutrazole, both in the plant and in the soil (Whiley, *et al.*, 2013), making it a more accurate tool. The timing of application is critical and recently there has been growing discussion around the effectiveness of the generally accepted application window. Table 2 summarises the various treatment times.

PHENOLOGY	**METHOD**	**COMMENTS**
Mid-bloom	Foliar 2L/ha or 1% concentration	This is the generally accepted application window and the one that much of the literature refers to (Wolstenholme, *et al.*, 1990; Whiley, *et al.*, 1991).
First Flush (20cm) – late spring	Soil 4L/ha	Generally applied in the southern hemisphere in late November, early December to manage the vigour of the first flush that begins during flowering.
Second Flush - summer	Soil 2-4L/ha	Used in cases where excessive vigour may limit a flowering response the following spring either in young trees or in regrowth from pruning.

Table 2: PGR Application Windows (author)

The mid-bloom application, while still the most widely used, is coming under scrutiny due to the role gibberellins play in pollination such as pollen tube growth (Smith, *pers. comm.*, 2018). Indeed, one consultancy group in Chile (GVCAgro) is actually *applying* gibberellins pre-flowering to try and delay flower opening (Bories, *pers. comm.*, 2018). Soil applications were popularised by Mena and Gardiazabal from the Gama group in Chile (Gardiazabal, *et al.*, 2011; Mena, *et al.*, 2011; Mena, *pers. comm.*, 2018) and are perhaps the more accurate method of application since the PGR, transported in the xylem, is taken to the newly expanding leaves of the flush at which it is aimed and is not translocated to other plant organs. Good results have been achieved using this method.

The avocado conforms to Rauh's architectural growth model (Halle, et al., 1978) in which continuous episodal growth of between two and four vegetative flushes per season adds to the size of the tree. Without intervention the avocado tree will just get bigger and bigger. In addition to this problem, the dense canopy that forms in healthy trees restricts light penetration to between 20cm and 1m (Hadari, 2004). These two factors require some sort of growth management in order to keep the tree productive. Pruning and PGRs are effective tools that can be used in achieving this, but they need to be used judiciously since poor timing or selection of limbs can lead to disastrous yield consequences. In addition, the producer needs to take into consideration the crop load of the tree which in itself is a restriction on vegetative growth. Further, the tools of pruning and PGRs cannot be applied in isolation since many other orchard factors influence the success or failure of a certain system. The following chapter attempts to summarize all these factors in diagrammatic form.

Chapter 6: An Integrated Management Model

Liebig's Law of the Minimum (Reilly & Fuglie, 1998) can be used to describe the success of an agricultural system as a function of the scarcest resource. This is an important consideration in implementing a HD production system and Figure 24 tries to encapsulate all considerations in setting up and running a HD project.

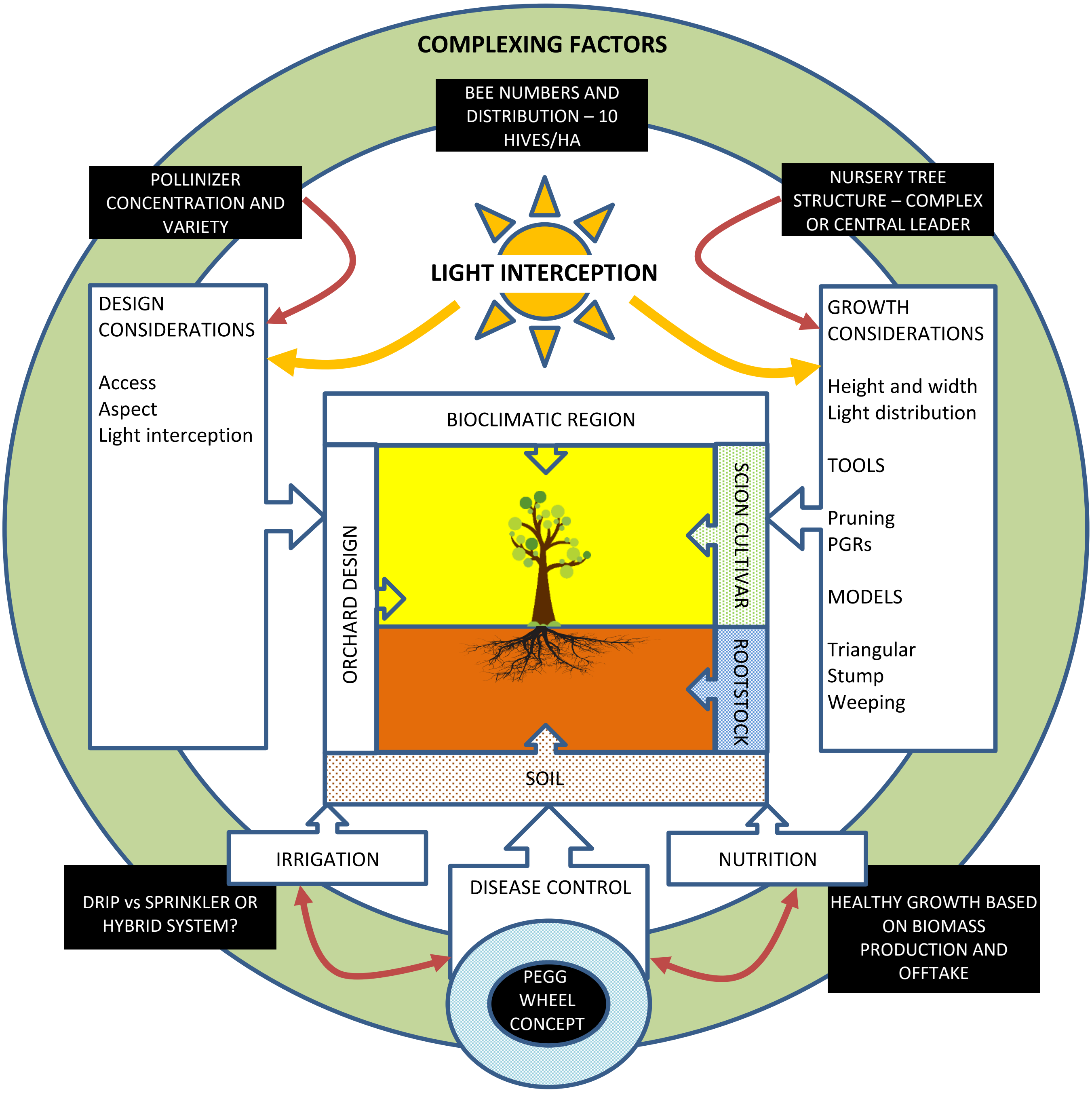


Figure 24. Considerations in HD systems (Reilly & Fuglie, 1998)

Conclusion

High density avocado production is in its infancy although interest to implement such systems is gaining momentum among top producers.

Varietal selections of rootstocks and scions currently available do not suit intensive production systems meaning that physical and chemical manipulation of tree growth is necessary.

In order to utilise these tools effectively the underlying requirements for high production need to be understood. These include high light interception and good light distribution which in turn rely on orchard design, tree architecture and tree health.

It is possible to integrate these requirements into an orchard management system that is based around a pruning model selected according to management intensity and the willingness to use PGRs. However, it must be emphasized that in order to maximise returns, all aspects of orchard management need to be optimised and it is recognised that agricultural systems are complex and dynamic and that the systems adopted must be flexible enough to adapt to a changing environment both physically and technologically.

Recommendations

High density production systems in the avocado industry are a viable concept and can be used to improve productivity from a given set of resources.

However, like any system, success lies in implementation and there are a number of recommendations that should be considered:

- Not every region is suitable. Highly invigorating environments such as those found in the tropics and warm subtropics will find it difficult to control growth without intensive management and high rates of use of PGRs.
- UHD systems may not be suitable in Australia due to machinery access issues.
- Healthy trees are the key to success, so the management of PC is critical.
- Understanding the principles of light interception and light distribution is integral to proper implementation of pruning practices.
- Future avocado production will migrate toward more horticulturally friendly Hass-like varieties, but uptake may be slow and reliant on vigorous testing in sub-regions. Therefore, industry leadership should be looking to be involved in the global selection of new varieties for rootstocks and scions through AVIP and implementing widespread trials.
- Uptake of HD systems may be restricted to those operations that have the management capability, and for these businesses it cannot be over emphasized that the success of the system is dependent on the adoption of a 'whole of orchard' management view where HD is not a bolt-on module but an integrated growing philosophy.

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Plain English Compendium Summary

Project Title:	High Density Avocado Production: Constructing an Integrated Management Model
Nuffield Australia Project No.:	1809
Scholar:	Dudley Mitchell 23a MacQueen Crescent Bunbury, WA 6461
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Objectives	• Outline key principles for high density production • Present a global perspective of high density production systems and methods • Discuss the extrinsic factors affecting the success of high density systems • Summarise the intrinsic orchard management practices that can be used to manipulate growth • Present an integrated diagrammatic model for high density production
Background	There is a need in the avocado industry to increase productivity from limited land and water assets to counter price declines as a result of oversupply in the absence of a limited and under-developed export markets.
Research	Investigate high density production in other areas around the world and assimilate the knowledge into a simple integrated orchard management model suitable for Australian conditions. The research will cover industries in South Africa, California, Chile and New Zealand.
Outcomes	High density production is a viable tool to increase productivity but is not appropriate to all areas. Intensification of production requires more management input and knowledge. Current varieties and rootstocks are not well suited to high density but newer varieties will be more horticulturally friendly.
Implications	A simple model is presented for the implementation of high density production outlining the major decisions and their implications as well as confounding factors.
Publications	Presentation at 2019 Nuffield National Conference, Brisbane QLD