ULTRA HIGH DENSITY AND THE VALUE OF TRELLISING: A CASE STUDY OF ‘MALUMA’

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Summary

Keywords: Practices, Production, Profitability, Pruning, Technique, Yield,

In most commercial crops, such as deciduous fruit, high density plantings and especially the use of trellis or training systems has improved production to previously unimaginable heights.

However, in avocado production the move from 204 trees/ha to 357-408 trees/ha was marked as high-density production, yet very few gains were seen and sometimes with more detrimental effects such as alternate bearing due to non-specific pruning practices. With high temperatures and an industry characterised by growth vigour, South Africa’s climate was not suitable to high-density production of Hass as in countries with more beneficial climates such as Chile. Yet with the dawn of ‘Maluma’ as a semi-dwarfing dark-skin cultivar, high densities became viable and even without the use of growth regulators such as Paclobutrazol and Uniconazole.

This study follows the production of two research plots as well as a 1.9 ha commercial orchard planted on 4m x 2m (1250 trees/ha) trained on vertical and Tatura trellis (2500 trees/ha). The system is built on 800mm high ridges with 1 litre/hour drip irrigation. The commercial orchard also contains a design of 3 different inter-wire distances (150mm, 200mm and 300mm) repeated over the 48, 100m long rows. Production results over these different wire distances are used for comparisons. During the 2019 harvest seasons the second commercial crop will be harvested and the trees will reach full maturity in terms of production capacity.

Globally trellises are used for many reasons on other crops ranging from wind protection, yield and pruning improvements as well as many other factors. Three years’ results have shown many benefits to the use of trellis on ‘Maluma’ such as improved quality, fruit size consistency, volumetric (efficient) yield improvements and others. Furthermore, two of the three wire distances are performing 10-20% better on production. 12-16 t/ha production is already achievable in the third year after planting and, without adapting planting densities, even yields as much as 50% more were produced on the trial compared to control blocks.

For the first time a micro management pruning and training model has been developed to improve the intensity with which avocado farming can be conducted with precision to improve output through increased production.

Introduction:

A key to higher production is improved pruning practices, yet to do this we need a better understanding of the bearing pattern of the tree (Iturrieta, 2019). Trellising provides a crucial first step in this as the visual identification of branches are simplified although complexity is increased.

Over the last decade Allesbeste, located in Tzaneen, South Africa, has been trying to find the holy grail for producing on high density and ultra-high density in warm climates. According to
Wolstenholme and Sheard (2012) high density is at tree population between 500-1000 trees per hectare and ultra-high density 1000+ trees per hectare. In comparison with cooler climates or microclimates with restrictive soils and temperatures, hot climates are characterised by growth vigour and reduced production and most likely fruit size (Wolstenhome & Sheard, 2012; Köhne, 1988). Furthermore, with conventional orchards already producing lower than in margin climates, the move from standard densities to high densities produced a further challenge. Avocados produce crop on terminal shoots, which are decreased through rigorous pruning regimes, which furthermore increases growth vigour and reduces production (Toerien & Basson, 1979).

After 6 years of experience of producing ‘Maluma’ on densities of 800-1600 trees per hectare, many benefits were realised in the high-density production of avocados.

Benefits included improved harvest rates as well as improved initial and therefore cumulative production. Similar to the findings of Köhne and Kremer-Köhne (1991) with one exception, that with semi-dwarfing ‘Maluma’ no plant growth regulators (PGR’s) were used. Furthermore, there was also a strategic advantage to developing high density orchards as to produce the same amount of fruit on the same number of trees in year 1 to 4. Less money was spent on development as the same number of trees was planted on less hectares. Effectively reducing development costs. Yet annual production of mature orchards was similar to conventional densities.

In many industries trellising or training systems have been implemented with great success, especially to improve yield beyond previous production norms for those industries. The most common benefits were increased sunlight penetration, improved orchard management, improved disease and pest control, improved spatial utilisation, precocity improvements and thus improved return on investment (Micke, Tyler, Foott, Smith, 1976; Unknown, 2017; Staff, 1993). The decision was taken to determine which of these practices from other industries could be implemented and its effects on avocado production monitored, therefore also the aim of this study.

One of the major reasons for introducing trellising as an option was the lack of sunlight reaching the lower branches of higher density ‘Maluma’ trees in central leader systems. Initial production was magnificent on trees planted on densities 800trees/ha and higher, from year 3 onwards production declines due to branches higher up in the tree bending downwards and overshadowing lower branches. Some branches within the trees would extend downwards as far as 1,5m. This had a major negative effect on cumulative production in the long run. Also presenting a pruning challenge.

Based on the growth pattern of ‘Maluma’, being a semi-dwarfing tree, it was assumed that trellising would be viable in terms of improving on the production norms of avocados in South Africa. The first commercial block of trellising was established in 2016 after initial trials were started late 2015.

**Materials and Methods**

Three commercial orchards were compared for the trial:

**Orchard 1 – Control 1: Conventional High density:**
Cultivar: ‘Maluma’
Rootstock: Bounty and Duke 7  
Planting date: December 2013  
Density: 800 trees per ha  
Tree spacing: 5 x 2.5m  
Irrigation: Micro

Orchard 2 – Control 2: Conventional Ultra-high density  
Cultivar: ‘Maluma’  
Rootstock: Various Rootstocks  
Planting date: December 2015  
Density: 1250 trees per ha  
Tree spacing: 4 x 2m  
Irrigation: Low flow drip

Orchard 3 – Trail: Ultra-high density with Vertical and Tatura trellis systems.  
Cultivar: ‘Maluma’  
Rootstock: Bounty  
Establishment date: April 2016  
Density: 1250 trees per ha  
Tree spacing: 4 x 2m  
Irrigation: Low flow drip

In Orchard 3, the commercial trellis block, three different wire spacings were used. Wires were spaced 150mm, 200mm and 300mm apart on a vertical trellis. The first wire on 450mm above the planting ridge and then evenly spaced from there on upwards to a maximum height of 2,1m. The decision was taken not to increase the height of the tree to the norm of 80% of row spacing which would be 3,2m as a manageable height was a priority and there was ambiguity about the manageability of higher trees on this system. Ridges in this case were 800mm high, which means that effectively the tree height was 2,7 meter measured from the orchard floor.

To create a manageable randomised planting system, it was decided to erect the structures with the same wire spacing 3 row repetitions at a time. As per the Figure 1.

![Figure 1: Trellis orchard layout.](image-url)
Furthermore, a Tatura (or V-trellis) structure was erected on 7 rows. 3 rows where the trees were split into two main leaders for each side of the ‘V’ and 4 rows where additional trees were planted to increase density to 2500 trees/ha.

Production was measured on a row basis, by weighing every harvest bag, and accumulated for each wire spacing to do a comparison.

**Figure 2:** Vertical trellis (left) and Tatura trellis – split tree (right).

**Results:**

<table>
<thead>
<tr>
<th>1st Harvest (Year 2)</th>
<th>2nd Harvest (Year 3)</th>
<th>Cumulative improvement to Control 1 (%)</th>
<th>Cumulative improvement to Control 2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest 1</td>
<td>Harvest 1</td>
<td>Harvest 1</td>
<td>Harvest 2</td>
</tr>
<tr>
<td>Control 1</td>
<td>3.7</td>
<td>2988</td>
<td>10.4</td>
</tr>
<tr>
<td>Control 2</td>
<td>4.0</td>
<td>5062</td>
<td>69%</td>
</tr>
<tr>
<td>Vertical Trellis - Total</td>
<td>2.6</td>
<td>2978</td>
<td>0%</td>
</tr>
<tr>
<td>300mm Vertical Trellis</td>
<td>2.6</td>
<td>3238</td>
<td>8%</td>
</tr>
<tr>
<td>500mm Vertical Trellis</td>
<td>2.9</td>
<td>3606</td>
<td>22%</td>
</tr>
<tr>
<td>150mm Vertical Trellis</td>
<td>2.4</td>
<td>3000</td>
<td>0%</td>
</tr>
<tr>
<td>Tatura Trellis ***</td>
<td>1.5</td>
<td>1875</td>
<td>-3%</td>
</tr>
<tr>
<td>Vertical Trellis (calc) 3x1.5</td>
<td>2.6</td>
<td>5752</td>
<td>93%</td>
</tr>
</tbody>
</table>

*** Tatura trees are approximately 6 months younger than Vertical trellis

**Table 1:** Production table.
Figure 3: Production comparison in kilogram per hectare.

Figure 4: Cumulative production statistics.
Figure 5: Tree production uniformity comparison in kilogram.

Figure 6: Ten year ‘Maluma’ count spread average.
Figure 7: ‘Maluma’ trellis count spread.

Figure 8: Conventional orchard quality grading.


**Figure 9:** Trellis orchard quality grading.

**Figure 10:** Uniconazole application and control

**Discussion:**

*Importance of sunlight for production*

With trellising a definite improvement has been seen on flower pollination. According to Iturrieta (2019), conventional avocado orchards produce more than 2 fruit per shoot on only 10-12% of shoots, whereas with ‘Maluma’ on trellis this ratio improves to 22.5%. This is confirmed as per Figure 11 where the fruit tends to hang in clusters of bunches rather than as individual fruit. This is an indication of fruit set percentage being higher per inflorescence than on conventional trees were only one or 2 fruit is located per inflorescence.
Furthermore, the effect of light penetration can also be seen (Figure 12) on the development of spurs on the main laterals extending from the central leader. Consequently, production does not keep moving to the end of the branch but remains throughout the branches of the tree. Branch differentiation together with increasing the complexity of the tree increases production and reduces the chances of alternate bearing (Iturrieta 2019). Yet on conventional orchards increased complexity is often too difficult to obtain, and once obtained it is often counterproductive as less sunlight reaches the base of the tree. The extent to which this differentiating growth on the laterals can be stimulated in the future to even further improve production is expected to be determined by the improvement and the development of pruning practices.

*Figure 12: Branch differentiation and the development of spurs.*

*Increased flowering and fruit set potential*

Productive branches only represent the first 500mm – 1500mm into the tree from the canopy of the tree, on all sides of the tree. According to Stassen, Snijder and Bard (1999) shading in trees cause decreased flower-bud formation and decrease in fruit size in apples. Lakso and Robinson (2014) also confirms that light inception increases from 40 - 80% improved apple production by approximately 50 tonnes per hectare. With this in mind it is crucial to manage light penetration into the tree. What we’ve seen on trellis is that as the tree shape has changed
tremendously and with structural lateral branches being tied to wires the light penetration is potentially 100% on all branches.

Since introduction of the orchard on trellis major improvement in the flowering of the three has been noticed. Notably often flower buds even develop from the bark of the tree or even on the shoots itself. This uncommon flowering could only be explained by the increase in sunlight.

Although flower occurs on the inside of a tree with conventional methods, these flowers show lower fruit set than exterior flowers on conventional trees. In the case of trellising there is theoretically no inside or outside to the tree due to its flat structure and with this 100% light penetration all flowers are exposed to sunlight during the flowering stage. This, as per Figure 8 above, is clearly visible in the development of fruit cluster. One of the main explanations behind this is the improvement of flower bud development and pollination due to improved sunlight exposure to the lateral branches and flowers.

**Yield comparison between conventional orchards and trellising.**

Trees on the trellis orchard were established approximately 8 months before installing the trellises. The negative effect of this is that vigorous pruning had to be done a month before flowering. This removed many productive branches on trees and also caused the trees to react in a vegetative manner.

Despite this trees still achieved a tremendous tree growth, as can be seen in Table 1 when comparing year one’s yield data of Vertical trellis (total) to that of the control, no improvement on production is seen except for that of the 200mm wire spacing. The ideal for trellis orchard development is that training of the trees need to be initialised directly after planting to minimise the effect of pruning. Therefore, it is expected that even though year one’s yield is similar it should be much higher than the control already. It can also be noted that at this point the trellis was lagging behind the second control, which is also a 4 x 2m planting conventional orchard. Approximately 2,1 tons less was harvested on the trellis at this point compared to control 2. Yet production was higher than control 1 by 22%. By comparing the best spacing at this point, the 200mm was lagging behind by approximately 1,5 tons. Note however that in year two the 200mm spacing had 3,6 tons higher production than the conventional production on control 2. Which is a 28% increase in production.

When looking at cumulative production after 2 years it can be noted that the average of the total trellis orchard is pulled down tremendously by the weaker production on the 150mm spacing. On the other two spacings, 200mm and 300mm, the cumulative production over two years was 212% and 219% higher than the control 1 and 9% and 12% higher than control 2 respectively. This is significant increases in production and have proven to have a positive effect on the return on investment of an orchard.

It is crucial at this point to also highlight that control 2 has practically reached full maturity where volumetric production will only increase marginally. Whereas on the trellis there is still 30 to 50% of the trellis space available for growth of the trees (see Figure 16), and it is therefore expected that production capacity can still increase tremendously. There is therefore no doubt that the trellis production will remain higher.

*Tatura trellising.*
The main objective of Tatura trellising is to optimise on volumetric production capacity of the tree or simply put the surface area of the tree that has the ability to crop. This is done by splitting the tree in two and theoretically having double the tree surface area.

In terms of flowering the “V-shape” of the tree has tremendous light exposure on the inside of the tree which is evident in the flower formation (Figure 2 - right). The main benefit here is that fruit set occurs on the inside of the V where maximum sun exposure occurs. Yet, once fruit develops and gains weight, the drop through the tree structure to the bottom ends of the “V” which effectively protects the fruit to optimise on fruit quality.

Although cumulative production is lower than the other trellising options and very similar to the control, we do see great potential in Tatura trellising. The Tatura was set up on a low percentage (12%) of the larger trellising trial and also in an isolated area without repetitions, in an area over shaded by indigenous trees.

What is encouraging is the fact that on trees 6 months younger than the Vertical Trellis 14 tons/ha was achieved which is well in line with the vertical trellis production. Thus the biggest shortfall was on initial production which could also be explained by the 6 months loss in growth.

Quality comparisons

One of the biggest concerns and criticisms against trellising is the effect light penetration and reduced tree structure would have on fruit quality and sun burn.

Based on commercial pack house reports trellis quality was not adversely affected. One of the most viable explanations to this would be because of phototropism. Phototropism is the natural tendency of plants to grow towards sunlight. With the current trellis planted on a north-south row direction, and the warmer side of the tree in the Southern Hemisphere being the western side, the same natural tendency was visible with regards to vegetative growth. The main advantage here was that regardless of how narrow the tree structure was and the aggressiveness of pruning, flower and fruit set was exposed to sunlight where after trees soon closed up on the western side of the tree preventing sunburn.

Fruit size comparison between conventional and trellising

As per Figure 6 and Figure 7 above it can be clearly concluded that trellising has a significant effect on fruit size during the first two years. A 6% increase in count 14 (4kg) and 8% increase in count 16 (4kg) has been achieved. Interesting to note is that the variance in count size have also reduced. On trellis count 12, 14 and 16 (4kg) comprises 55.2% of production, whereas on conventional orchards the same counts represent only 42%. As orchards grow older it is expected that fruit size will decrease slightly. Yet, we do expect less small fruit as trellis orchards require continuous rejuvenation of productive branching. Fruit size uniformity is also clearly visible on Figure 13 below.
One of the major objectives of this trial was to determine an optimal wire spacing for trellising avocados. With differences in pruning and training techniques wire spacing will have different effects on yield. A consistent training method was applied.

Initially the assumption was that 150mm spacing on wires could potentially produce the most fruit as there would be a higher quantity of productive laterals structured on the trellis.

On evaluation of Table 1 above it is however clearly visible that the 200mm spacing and 300mm spacing produce almost equal yields while the 150mm was lagging behind. The main assumption is that with the 150mm spacing wires are spaced too close to each other preventing sufficient light penetration. Should the yield characteristics of the 300 and 200mm spacings continue, the conclusion is that 300mm would be more viable as the cost of the structure is adversely affected by the increase in wires from 300mm to 200mm, with a decrease in the return on investment.

As per Figure 14 below it is also clear that the pedicel of the fruit and how this varies between cultivars will affect the wire spacing. The conclusion is that it is not ideal for the fruit die hang past or below the next wire as this will have an adverse effect on sunlight penetration. On ‘Maluma’ 300mm seems to be the best wire interval or spacing. One of the biggest benefits of trellising through this method is the ability of mechanical harvesting in the future.
Uniconazole applications

Although uniconazole applications on flower is a standard practice on all Hass at Allesbeste in Tzaneen’s warm climate no applications have ever been used on ‘Maluma’ due to its less vigorous growth. On year one’s production it was therefore decided not to use any plant growth regulators (PGRs). It was however noted that PGRs might have a beneficial effect in terms of vegetative flush control after flowering during fruit growth to prevent fruit drop.

During year 2 PGRs were applied in 3 applications of 4 litres per hectare. A mistblower was used with a light cover. These applications were not spaced at a particular interval but based on evaluation of the vegetative bud break and flush development.

In terms of the uniconazole applications in comparison (Figure 10) with the control no significant changes in crop was noticed. The average production with the control in the uniconazole trial was 13kg/tree. Average production with the uniconazole application was 13,3kg per tree. This is merely a 2% increase in production. Noticeably however change in fruit shape was noted. Figure 15 illustrates left the regular fruit shape (piriform) of ‘Maluma’ fruit and right the more round shaped uniconazole treated fruit.
Optimal tree height and density

As this was a new venture many unknown factors existed in the setup of the structures as well as how the avocado tree, in particular ‘Maluma’, would react to trellising. Keeping in mind that the tree height norm on conventional orchards are 80% of row width. On the 4m spacing we would not want trees higher than 3.2 meters. The ridges on which trees were planted was approximately 800mm high. Taking that into account we did not want the trees to exceed 2.4m to ensure even light penetration into the orchard. Yet in retrospect, mostly due to the difficulty of managing trees on such high ridges, new orchards were developed with ridges no higher than 400mm. Even regardless of ridge height new trellises will be allowed to grow higher to further increase the production capacity of the orchard. The 400mm ridges will just make trees, especially during pruning and harvesting, more manageable. It is firmly believed that trees can be grown safely up to a height of 3-3.6m without affecting the manageability of the orchard.

Assuming that the orchard is established on 4m x 2m spacing, with 200mm wire spacing it can be calculated that an increase in height can further improve cumulative production at year two by doing the following calculation.

Current production: 16 661kg /ha
Current amount of wires 11
Is therefore 1514 kg per wire per hectare.

It can thus be derived that by adding additional wires could potentially increase production by 1514kg per wire per hectare. By increasing tree height to 3 meters will add an additional 3 wires which could potentially increase production by 4.5 tons per hectare to 21 204 kg/ha. This would then provide a 55% increase in yield on control 2. The assumption is that trees would not have grown beyond 3 meters by year 2 and therefore no calculation beyond this height will be made.

In terms of tree density and planting distance it can still be noted after year two that trees have not yet fully reached maturity and the inter-tree spaces have not yet been filled (Figure 16 below). Furthermore, trees are much narrower than expected. The assumption can therefore be made that trees could be planted on an even higher density to optimally produce on space.
available. 3m x 1.5m seems to be a very viable option to achieve this and the assumption can be made as per Table 1 that 145% and 95% respective increase in production in comparison with the two controls will be achievable on this higher density.

![Figure 16: Inter-tree spaces not fully utilised after completion of year 2 on trellis.](image)

**Future research**

- First commercial dedicated Tatura trellis
  Allesbeste has planted a full commercial Tatura orchard during 2018 and this could potentially provide more insights into the management options and viability of Tatura trellising. Densities were also increased on sections of this orchard to determine the feasibility of a 2500 trees per hectare Tatura trellis with staggered planting.

- Plant growth regulators (PGRs)
  More research can be done on the timing of treatments and the different PGRs available. Concentrations and method of application and its effect on trellising and yields will also be important. Currently uniconazole is the most frequently used product and will therefore be the chemical of choice, yet trials will also be done with paclobutrazole. In South Africa uniconazole is not yet registered as a soil application and therefore paclobutrazole might be a good solution.

- Pruning timing to further improve flowering
  As only one commercial orchard has completed 2 cycles it would be important to evaluate the effect different timing will have on the flower development and trellis yields.

- Row direction
  The norm with avocados is to plant north-south. This has shown beneficial responses in tree quality of the tree, more research will have to be conducted. It would be important to determine the effect row direction will have on Tatura trees which are more prone to flower between the two axes (Left and right side of the ‘V’) of the tree. What effect would row direction also have on the timing of flowering and fruit quality.

- Angles of Tatura
  Moving from the vertical to the horizontal, avocado trees will produce more watershoots or bullshoots. Determining the optimal angle of a Tatura trellis would be an important
objective as this can have tremendous effects on growth vigour management and potential yields.

- Optimal densities and the effect of densities on orchard longevity.
  Very little is known about the real longevity of avocado orchards. Orchards as old as 60 years still produce competitive yields. Will trellising have an adverse effect on orchard longevity. Would there be an optimal age were, due to tree management and density, orchards would have to be replanted to prevent a decline in yield?

**Conclusion**

Trellising avocado orchards is successful with semi-dwarfing cultivars like ‘Maluma’.

It creates a production environment where trees can be managed on a micro level on high density and ultra-high density orchards. This creates the possibility for the first time to plan production within an avocado tree and to manage the tree on a shoot basis.

Trellising allows for optimal light penetration which improves flowering and fruit set.

Production is significantly improved through this improved management system and can be even higher through more meticulous management and installing structures prior to planting the orchard to prevent harsh pruning.

Trellising with semi-dwarfing cultivars such as ‘Maluma’ is not a difficult task. Growth vigour is light and easily manageable, even in warm sub-tropical climates like South Africa.

Thus far PGRs seem to be optional, yet it is firmly believed that in the future this will be one of the best tools to reach unimaginable production on avocados.

Although Tatura’s real production has not yet been established it confirms to be competitive to vertical trellises. It is undoubtable a good structure and it is expected that Tatura will surpass vertical trellis in a better planting arrangement.

‘Maluma’ reacted tremendously to being planted ultra-high density and being trained onto trellising. Production and fruit size increases has been seen and no growth vigour issues to date. Allesbeste has continued with its commercial plantings and during the winter of 2019 17 ha of commercial ‘Maluma’ orchards will be established under trellising.

**Acknowledgements**

Rodrigo Iturrieta for providing extra support and confidence in the trellising vision with his work on understanding the avocado language and in particular with ‘Maluma’ on trellis.

André Ernst for installing a vision of innovation and improvement at Allesbeste.
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