Preliminary results from the Small Tree – High Productivity Research Program

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ABSTRACT

Productivity in temperate tree crops such as apple has been lifted several fold by research focusing on optimising a combination of canopy components including light relations, vigour control, tree architecture and crop load. This paper outlines the research behind the Small Tree High Productivity Initiative (STHPI) which is focused on improving productivity of mango, avocado and macadamia. Preliminary results from work we are undertaking for each of the above canopy components in mango will be outlined. A rootstock screening trial to identify vigour managing, high productivity rootstocks is being undertaken and we present a comparison of the best performing low-medium vigour rootstock varieties compared to control Kensington Pride (KP) rootstock at six months old. Comparisons between Keitt, NMBP 1243 and Calypso scion varieties with regard to tree diameter, height and canopy growth at different orchard densities and training systems will also be presented. Preliminary results from an orchard light relations study indicate that mango yields continued to increase with light interception up to 50% and reached a maximum of 20-30 t/ha at 68% light interception in KP trees approximately 25 years old. In a crop load trial, inflorescence thinning in a Calypso orchard did not significantly reduce yields when up to 90% of inflorescences were removed but did when 95% of inflorescences were removed as trees were unable to compensate by adjusting fruit set, size and yield. Inflorescence thinning beyond 80% increased the number of fruit set per panicle and thinning up to and including 90% of inflorescences increased fruit weight from 340g to > 400g per fruit. This project is still in its initial stages, however early indications suggest there may be opportunities to improve early orchard yields through optimising light interception in an orchards life; potentially through the use of higher densities; and that rootstocks and tree training methods, once identified, may help in the management of vigour. It is also hoped to obtain a better understanding of how crop load influences the balance between vegetative growth, flowering, fruiting, alternate bearing and fruit quality.

Keywords: Mango, rootstock, crop load, vigour, light interception, training and pruning.

INTRODUCTION

Increasing tree density and changes to canopy dimensions may influence tree growth potential through increased light interception (Jackson 1980). This is because dry matter and yield are related to light interception (Hall et al. 1993). Although this may lead to increased dry matter production it may not necessitate increased yield due

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to aspects including competition for resources, age of trees and stress factors influencing photosynthesis (Johnson and Robinson 2000).

The upper limit of gross carbon assimilation is set by orchard light interception therefore the proportion of incoming solar radiation intercepted by the orchard is one factor that determines orchard productivity (Jackson 1980). The manner in which this radiation is distributed throughout the canopy is also important due to its effect on the development of fruit load, canopy efficiency and fruit quality. While orchard productivity is not only related to the canopy's ability to intercept light energy and produce photosynthates, there is also the ability of the canopy to convert this energy into harvestable fruits or nuts. In mango, the ability of the canopy to convert energy into fruit is controlled by a number of factors. These factors include inflorescence production, fruit set and retention and the effect of one season's fruit load on the development of flowers and fruit in the following season.

In addition, while the transition from large tree orchards to small tree high productivity orchards may lift orchard production, the control of vigour and management to maintain regular bearing are critical considerations for the adoption of the small tree orchard concept. It is expected that vigour control of the scion will be a significant issue in high density mango orchards therefore rootstock genetics and training and pruning techniques will be of considerable importance to the success of any high density venture.

The use of rootstocks is one method of transferring the low vigour onto regular high yielding scions (Reddy et al. 2003; Smith et al. 2003). It is important that this process screens large numbers of rootstocks from different origins, so that superior rootstock genotypes can be identified. Those selected need to be adequately evaluated, with subsets of desired characteristics tested in long-term field based trials to assess their consistency and suitability for commercialisation (Smith et al. 2003). In addition, there are new methods describing tree architecture and how components of tree growth, morphology and phenology are linked and it is the intention of this current research program to further develop this methodological approach (Normand et al. 2009).

The aim of this research was to investigate options for vigour control, crop load manipulation and light interception in mango orchards of different varieties, densities and training systems to better understand how mango responds with respect to growth, yields, tree size and fruit quality.

MATERIALS AND METHODS

Baseline crop load experiment

The aim of this research area was to develop a whole tree understanding of the relationship between inflorescence density, fruit set, yield and performance in the following year. This experiment was located at Dimbulah, Queensland. Soils at the site are broadly known as Chromosols (Enderlin et. al., 1997). In this trial 32 trees were selected in a commercial Calypso orchard located across 4 blocks, with each block containing 8 trees. Treatments were implemented on flowering panicles at full anthesis in September 2014 by removing proportions of inflorescences (0, 20, 40, 60, 70, 80, 90 and 95%) within the canopy of each tree. Total remaining inflorescences, fruit set over time, total yields, fruit size and canopy dimension were recorded subsequent to the treatment application.

Baseline light relations experiment

The aim of this work was to develop an understanding of the relationship between total orchard light interception, canopy volume and yield. These experimental sites were located at Southedge, Mutchilba and Walkamin in Queensland. Soils at each site are broadly known as Kandasols at Southedge; Chromosols at Mutchilba and Ferrosols at Walkamin (Enderlin et. al., 1997). Total light interception and productivity was measured using the following design methodology. 10 orchard blocks of different aged Kensington Pride (KP) trees were selected aging from 1 year to 27 years of age in the Mareeba /Mutchilba mango growing district in Queensland, Australia??? with trees representing varying sizes, levels of crowding and planting densities. Within each orchard block five trees were selected to represent an individual experimental unit except for the unmanaged 27 year old trees where only 3 trees were measured.

Using an AccuPAR linear ceptometer, the transmission of total photosynthetic active radiation (PAR) under the canopy of each tree was measured in June-July of 2014. The ceptometer was kept horizontal as shown by a level on the unit and measured at approximately 30 cm above ground level. Canopy dimensions (height, width, depth, skirt and trunk diameter at 30cm) were also measured in order to calculate tree volumes and yield per trunk cross-sectional area.

Light assessments were limited to full sunlit conditions. Measurements were taken at early morning (8 am), mid-morning (10 am), solar noon (12 pm), mid-afternoon (2 pm) and late afternoon (4 pm). The number of measurements taken was influenced by the direction of the rows. If rows run north and south light transmission was measured three times either before solar noon or after solar noon and the data repeated to represent the two measures not taken. Rows that were not north south were measured at each time period.

Prior to sampling light transmission, the plots underneath each tree were marked out using 10 m tapes and line-marking paint to delineate the total allocated space for each tree which includes the area from mid-way between trees in a row to mid-way between rows, both sides of the tree. Hence depending on the tree planting density, allocated tree area differed. The ceptometer readings were then measured end on end, the length of the distance between mid-points of two rows, along five transects. The five transects were from:

1. The centre point between two trees in the row (first plot);
2. Centre-point between first plot and tree trunk (the edge of the canopy);
3. Directly in line with beneath the centre of the tree,
4. Centre point between last plot and tree trunk (the edge of the canopy), and
5. The centre-point between two trees in the row on the opposite side of tree (last plot).

Each transect (plot) was marked at 0.8m (length of the ceptometer). Care was taken to avoid any shadows on the ceptometer bar from the person taking readings. The light transmission data was summarised using the following steps:

1. To ensure all trees have 5 time observations, missing times from north-south facing rows were replaced with the reciprocal time observation,
2. Light transmission was then calculated as a percentage of the below canopy PAR to upper canopy PAR. All light transmission values >100% were converted back to 100%;
3. Light transmission was then converted to light interception as 100 – light transmission.
4. The mean light interception for each tree, at each time observation was calculated;
5. The overall mean light interception for a tree was calculated as the average across all 5 means calculated in step 4.

Tree canopy volume (V/ m^3) and canopy surface area (CSA/ m^2) were estimated using the calculations $V=\pi r^2 h$ and $CSA=\pi r^2$ respectively. As well as light data, fruit count and size were taken and summarised for each age group within each site. The fruit yield of 5 tree plots (3 tree plots for 27 year old trees) was estimated prior to harvest by counting the number of fruit per tree and weighing a sub-sample of 10 fruit per tree.

Rootstock experiment

The objective of this experiment was to assess rootstock/scion interactions for vigour control (growth reduction) and dwarfing characteristics (morphological characteristics) of the scions. A series of trees were planted from a wide variety of *Mangifera indica* cultivars, from both monoembryonic and polyembyonic as rootstock sources, along with a number of *Mangifera* species. Other varieties of interest, such as those with desirable qualities like anthracnose disease resistance or those within the Anacardiaceae family, were also included. The aim was to graft a minimum of 90 rootstocks with two scions NMBP 1243 or 4069. Overall, this data summarises measurements of 104 potential mango rootstock seedlings, taken prior to grafting from 6–10 trees of each variety.

Trees were grown in a glasshouse at the Centre for Tropical Agriculture, in Mareeba (Latitude 17° 0'25.63"S, Longitude 145°25'47.75"E), Queensland between 2012 and 2016. Measurements taken included stem diameter (at 10cm above the soil level), tree height and the ratio of tree height to stem diameter assessed at approximately 6 months of age. Six months after grafting trees were planted out in the May of each year between 2014 and 2016 at the Walkamin Research Station, with the intention to replicate each scion/rootstock combination three times for each combination of scion/rootstock. Ongoing measurements of tree diameter, height, canopy dimensions, yield and precocity are ongoing.

Planting systems experiment

The aim of the Mango planting systems experiment was to integrate different mango training systems and planting densities, to lift orchard production and provide a platform for tree architecture and crop load research. This experiment was located at Walkamin, Queensland. Soils at the site are broadly known as Ferrosols (Enderlin et. al., 1997). The trial was designed as a split-split plot with density at the main plot level, training system at the sub-plot level and variety at the lower sub-sub-plot level. Each of 3 varieties (NMBP 1243, Keitt and Calypso) were combined with 3 densities (low, medium and high). Within the medium density there are 2 training systems: conventional leader and single leader. The high density plots also have 2 training systems: conventional and single leader trellis. The low density plot only has the conventional training system. Each density x training system is replicated 6 times. Tree height and diameter growth over time were used to calculate relative growth rates (RGR). RGR were assessed between 6 and 15 months after planting. Relative growth rate was calculated as growth (stem diameter (mm) or tree height (m)) at (time 2 – time 1)/time 1 * 100, where time 1 was at 6 months after planting and time 2 was 15 months.

Statistical Methods

Analysis of variance (ANOVA) was used to analyse the crop load and planting systems trial data. Where a significant effect was found, the pairwise 95% least significant difference (LSD) was used to make comparisons. Linear and non-linear models were used to investigate relationships between variables collected within the light relations and crop load experiments. Summary statistics were calculated for the rootstock nursery growth data.

RESULTS AND DISCUSSION

Baseline crop load experiment

Inflorescence number, canopy height, skirt, width, depth, volume and canopy surface area were not significantly different between trees before inflorescence thinning treatments were implemented. Inflorescence thinning led to a significant increase in final fruit set per panicle 1 week prior to harvest ($p < 0.001$) (Figure 1). Inflorescences thinned to above 80 % maintained 2 fruit per panicle whereas inflorescences that were not thinned (control), or thinned to 70% or less, had an average of one fruit per panicle. When fruit set was monitored over time there was a non-linear relationship between time and fruit set ($R^2 = 89.3\%$, $p < 0.001$, $n = 32$). The model indicated there was a large initial fruit drop in the canopy and as time progressed, fruit set in the canopy decreased.

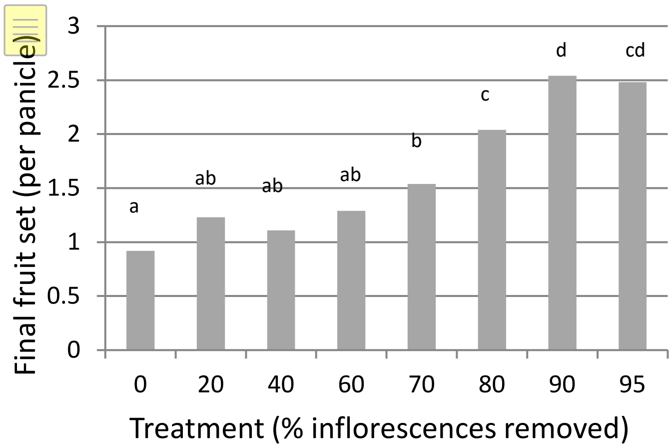
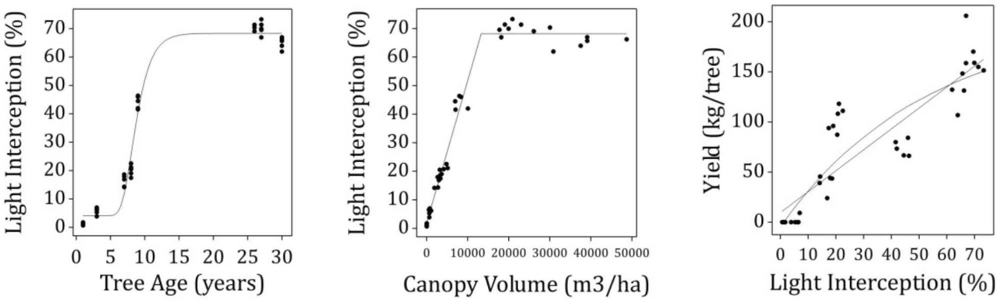


Figure 1: Effect of inflorescence thinning (% removed) and fruit set per panicle 1 week before harvest. Columns with a letter in common above them are not significantly different ($p<0.05$).

Mean fruit weight ($p < 0.001$) and fruit count per tree ($p = 0.008$) were significantly different as a result of inflorescence thinning (Table 1). While there was a positive trend of increasing mean fruit number up to 70% thinning, the only significant difference was at 95% thinning where there was significantly less fruit than all the other treatments. Reducing inflorescences significantly reduced the average fruit yield (Table 1), although it was only at the two highest inflorescence removals (90 and 95%) which showed significantly lower yields when compared to the control.

Baseline light relations experiment

There was a significant relationship between tree age and light interception where light interception does not appear to increase for trees between 25 and 30 years (Figure 2a). There was a significant relationship between tree age and tree yield (kg/tree) where yield decreases in trees after 27 years. There was a significant relationship between orchard canopy volume (m^3/ha) and light interception (%). A "broken stick" model estimated the upper limit for light interception as 68.2%. The model also suggests the light interception does not change for canopy volumes > 13319 m^3/ha (Figure 2b).



(a) (b) (c)

Figure 2: The relationship between tree age and light interception (%) for Kensington Pride mango trees (R^2=97.7%, p<0.001, n=39), (b) canopy volume (per ha) and canopy light interception (%)(R^2=98.4%, p<0.001, n=39), and; (c) between light interception (%) of the canopy and yield (kg $tree^{-1}$) (Linear R^2=77.8%, p<0.001, n=39, Quadratic R^2=78.5%, p<0.001, n=39) in Kensington Pride mango variety of different ages.

Relationships were also investigated between light interception and tree yield. Figure 2c shows the fitted linear and non-linear models for light interception and yield (kg/tree). The linear model explained 77.8% of the variation, while the exponential model explained 78.5%. The exponential model may be more realistic as it suggests that the subsequent increase in yield slows down at higher levels of light interception. However, over the range of light interception in this study, there is little difference in the fit between the linear and exponential models.

Rootstock

Rootstock seedlings were analysed according to height and stem diameter. A strong positive correlation between rootstock mean height and diameter (r = 0.798; p < 0.001, n = 104) was found and as a result the data were also presented as the ratio of mean height divided by the mean diameter (height to stem diameter ratio) and then ranked using this index (Table 2).

Previous mango rootstock research by Smith et al. (2003) found no correlation between potential rootstock seedling morphological characteristics (seedling height, trunk diameter, stem and leaf dry weight, leaf area per plant, average leaf size, internode length, bark thickness, bark percentage and wood and bark density) and the subsequent tree size yield, yield efficiency and average fruit size. However, this could be due to a few reasons. Firstly, in the experiment by Smith et al. (2003) mango trees were pruned for structure. Pruning forces a disturbance to the natural growth pattern and influences the trees size and shape, therefore disturbing the natural growth patterns of trees and influencing the architectural development of trees (Costes et al. 2006). In addition, the research of Smith et. al (2003) did not incorporate different scion/rootstock combinations, with the work limited to one scion (Kensington Pride).

Finally the research of Smith et. al. (2003) did not correlate the index of seedling height to stem diameter ratio. Normand et. al. (2008) found allometric relationships between leaf and stem characteristics in mature mangoes and linked these with functional relationships such as hydraulic and mechanical stem properties of mango cultivars from different evolutionary backgrounds. Hence measures of the seedlings at the nursery stage were included in this experiment to serve as a point of reference for comparing seedling vigour to other physiological characteristics not included in the work by Smith et. al. (2003). Examples of physiological parameters that could be compared with seedling data as potential indicators of dwarfing characteristics include phloem:zylem ratios (Rashedy et. al. 2014) or fine root density (Bithell et. al. 2014) in mature trees.

Table 2: Mean height and stem diameter (at 10cm above the soil) of the 10 most dwarf mango seedlings at six months after planting as a preliminary investigation for the Mango rootstock experiment.

Name	Ratio (height/ diameter)	Mean height (m)	Mean diameter (mm)	Rank
07.05.25	3.67	0.14	3.77	1
15011	3.82	0.28	7.39	2
OP.4069.071	3.99	0.20	4.93	3
Julie	4.04	0.45	11.16	4
Applanata	4.06	0.17	4.13	5
07.05.20	4.22	0.26	6.12	6
07.37.14	4.37	0.18	4.12	7
07.05.09	4.44	0.19	4.31	8
4043	4.50	0.25	5.62	9
Kerrie #1	4.512	0.16	3.463	10

Planting systems trial

Tree height relative growth rate

There was a significant interaction of density, training system and variety (p = 0.012) where the NMBP 1243 and Keitt high density conventional trees had a significantly slower RGR than the high density single leader trellis but the Calypso did not. Similarly the NMBP 1243 and Keitt medium density conventional training system trees, had a significantly slower RGR than the high density single leader trees, but the Calypso did not. In addition the single leader trellis training systems had a significantly slower RGR then the low density conventional training systems for each variety (Table 3).

Table 3: Comparison of means for height relative growth rates (%) for the interaction between density, system and variety for mango trees at between 6 and 15 months old, Walkamin, Far North Queensland. Means with a letter in common are not significantly different at the 0.050 level of significance when compared.

Density	System		Variety	
		NMBP 1243	Calypso	Keitt
High	Conventional	44.53 abcd	51.80 cde	51.09 bcde
	Single Leader Trellis	67.06 g	54.40 def	67.27 g
Low	Conventional	45.59 abcde	39.13 a	42.42 abc
Medium	Conventional	40.47 ab	43.01 abc	40.98 abc
	Single Leader	56.07 ef	46.22 abcde	64.49 fg

Stem diameter relative growth rate (10cm above the graft)

There was a significant main effect of density (p = 0.029) and variety (p < 0.001) for stem diameter relative growth rate (RGR). The high density trees had a significantly lower mean stem diameter RGR (68.0 %) compared to the medium density trees (75.4

%), while variety Keitt (63.8 %) had a significantly lower stem diameter RGR compared to NMBP 1243 (74.6 %) and Calypso (77.4 %).

Canopy length (along the plot length)

All main effects and interactions in the ANOVA were highly significant for canopy length ($p < 0.001$). For the conventional training system the mean canopy lengths, within each variety, were not significantly different between the three densities. The Calypso trees had significantly smaller means when compared to NMBP 1243 and Keitt grown at the same density and training system, except for medium density conventional trees (Table 3).

High density single leader trellis trees and medium density single leader trees both had significantly higher means when compared to the conventional training system for the same variety at high and medium density respectively. Within each variety the high density single leader trellis trees had significantly higher mean canopy lengths than the same variety grown using other densities and training systems.

Canopy width (across the plot)

All main effects and two-factor interactions (density x training system and variety x density) were significant ($p < 0.050$). In terms of differences between the training systems, the high density single leader trellis trees had a significantly smaller mean canopy width than all other combinations of density and training system. The medium density single leader trees had a significantly higher mean canopy width (Table 4). Calypso had the smallest mean canopy width at all densities but it was not significantly lower than Keitt at the high density. No significant differences were found between NMBP 1243 and Keitt within each density.

Table 4: Comparison of means for canopy width (m) for the interaction between density and variety for mango trees at 15 months old, at the planting systems trial, Walkamin, Far North Queensland. Means with a letter in common are not significantly different at the 0.050 level of significance.

Density	Variety		
	NMBP 1243	Calypso	Keitt
High	0.73 b	0.63 a	0.67 ab
Low	0.93 cde	0.72 ab	0.90 cd
Medium	0.95 de	0.85 c	1.00 e

Within each variety significant differences were found between the mean canopy widths for each density. For NMBP 1243 the mean at the high density was significantly smaller than at low and medium densities, but there was no significant difference between the means at low and medium density. The means for high and low density were not significantly different for Calypso, and both of these were significantly lower than at the medium density. Significant differences were found between all three densities for Keitt, with the smallest mean canopy width occurring at high density, followed by low density and then medium density. For all three varieties the smallest means occurred at high density, followed by low and then medium density.

CONCLUSIONS

Although these results are preliminary, early research has shown training systems and mango rootstocks can influence tree growth and that crop load manipulations can influence fruit number and size. Finally, while standard mango orchard planting configurations reach maximum production and light interception between 10 and 25 years there may be potential to reduce time to maximum production by optimising light interception earlier using more closely spaced trees.

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