# Effect of crop load management and canopy architecture on yield and fruit quality of late-season plum 'Angeleno'

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***Abstract***

**The Australian summer fruit industry has identified that sales growth is impeded by low consumer satisfaction with fruit quality, leading to low prices and static consumption. Crop load is known to affect fruit size of plum, but few studies have been reported on fruit quality. The effect of crop load on fruit quality was studied in an experimental orchard at Tatura, Australia. The objective of the study was to identify crop load management practices, under Tatura trellis and vase training systems, to enable plum to maximise uniformity in fruit quality attributes. Different thinning regimes were implemented in season 2016/17 to establish the following crop load treatments: 1) high: minimally thinned; 2) medium (commercial standard as control): moderately thinned and; 3) low: heavily thinned. Larger canopies occurred on Tatura trellis compared to vase, despite identical tree density and age. Larger tree size was reflected in trunk cross-sectional area and canopy radiation interception ($f_{PAR}$), providing capacity to support greater fruiting levels and high yields. Mid-season $f_{PAR}$ was ~68% under Tatura Trellis compared to ~52% for vase trees. Fruiting level did not affect full bloom date in spring 2016 and spring 2017 or $f_{PAR}$ in summer 2017 for a given canopy architecture. However, trunk growth was higher under low crop load on Tatura trellis. Overall, high cropping levels reduced fruit weight and lowered pack-out performance. Irrespective of training and cropping level combination, fruit sweetness was high (≥17.2 °Brix), with low variability (CV≤11%). Over half of all fruit grown on Tatura trellis exceeded 18 °Brix, compared to ≤38% on vase. For vase trained trees, fruit maturity and firmness were similar across crop load treatments. However, for Tatura trellis training system, high cropping levels produced more immature and firmer fruit.**

**Keywords:** firmness, maturity, planting system, sweetness, thinning, uniformity

## INTRODUCTION

The majority of Australia's plum production (~26,000 t), valued at AUD$ 52 m, occurs in the Goulburn Valley of Victoria. Approximately 58% of fruit is consumed fresh domestically, with 27% processed and the balance (~15%) exported, primarily to Hong Kong and Singapore. The Australian summer fruit industry has become focused on export prospects, with China representing a major growth opportunity, with Chile being Australia's main competitor. The industry has the potential to grow fruit to market specification, taking advantage of new and existing free trade agreements with Asian countries, driving up export volumes, creating new niche markets for premium products on the domestic market and receiving a premium price.

Plums offer human nutrition benefits via high fibre and antioxidants (Kim et al., 2003). However, sales growth of summerfruit is impeded by low consumer satisfaction with fruit quality, leading to low prices and static consumption, which is threatening the survival of many producers.

These trends pose a major threat to the growth and viability of the domestic industry, which is also experiencing increased competition from other seasonal crops including mango

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and table grapes. Variable fruit quality, particularly in taste and texture, and general consumer dissatisfaction have been identified as the major impediments to increased sales on both domestic and export markets. Summer fruit is primarily sold loose and priced $kg^{-1}$, but a growing trend of retailers is to sell pre-packed fruit to drive sale volumes.

Agronomic techniques can manipulate the source-sink ratio and assimilate partitioning to fruit. In this study, we examine the effects of modifying sink size (crop load) via thinning on yield, fruit size and sweetness outcomes. Fruit thinning activities contribute to the cost of orchard production via labour required; however, low crop loads offer savings through reduced picking, packing and transport costs.

To the best of our knowledge, there is limited information available on the effects of crop load on fruit quality attributes, particularly sweetness and tree growth effects for summer fruit crops (Lopresti et al., 2014). For plum on Tatura trellis canopies in a sub-tropical environment, showed thinning to one fruit $cm^{-2}$ trunk cross-sectional area resulted in an increase in fruit soluble solids concentration of ~0.5 °Brix, and an increase in fruit weight by ~10 g. Optimal fruiting levels are important for orchard management as they govern labour costs, yield and final fruit size. Strategies to target export specifications for high quality fruit therefore need an optimisation of the balance between vegetative growth, marketable yield and labour and fruit handling costs.

The objective of the study was to identify crop load management practices, under Tatura trellis and free-standing vase canopy configurations, to enable plum 'Angeleno' on Myrobalan H29C rootstock to maximise uniformity in fruit quality attributes. The effect of crop load on fruit production was studied in a designed field experiment at Tatura, Australia. The crop loads to induce maximum, moderate and minimum responses of competition between fruit and available assimilate, viz., 1) high: minimally; 2) medium (control): moderately and; 3) low: heavily thinned regimes, respectively were implemented in season 2016/17.

## MATERIAL AND METHODS

### Experiment conditions

The experiment was conducted on 3-year-old plum trees (*Prunus salicina* L. 'Angeleno') on Myrobalan H29C rootstock at Tatura (36.43°S; 145.28°E, elev. 114 m) in SE Australia. *Prunus salicina* L. 'Tegan Blue' on Myrobalan H29C rootstock were planted every tenth tree as pollenisers. Climate is temperate, and rainfall is evenly distributed throughout the year. Irrigation is used to counter the high evaporative demand experienced in summer months. Irrigation requirements were determined using a weather-based evapotranspiration FAO-56 approach with a crop coefficient adjusted for tree size, measured as the fractional photosynthetically active radiation (PAR) interception ($f_{PAR}$). Irrigation water was of high quality and applied daily via a single drip line comprising of in-line pressure compensating emitters (1.6 L $h^{-1}$ discharge, 0.5 m spacing). Between-row and between-tree spacings were 4.5 and 1.0 m, respectively, in north south tree rows of a 3-ha experimental stonefruit orchard. Trees were trained as Tatura trellis and free-standing vase canopy configurations. Trees were irrigated, fertilised, pruned, and pest/disease managed according to established local commercial practices.

### Treatments

Fruit were hand thinned during October (77 days after bud burst, DABB) to establish the different crop level treatments. Thinning was undertaken by the initial removal of fruit clusters, and an even thinning of remaining fruitlets to the desired crop load target. Both Tatura trellis and vase experiments had three crop loads (high, medium, low) as treatments. Fruiting levels of the medium (control) crop load treatment were set to represent current grower 'best practice' to maximise fruit size and fruit sweetness. The protocol used for the control trees was to target a cropping level of ~1 fruit 10 $cm^{-1}$ of fruiting lateral and, thin fruit (fruit <12 mm diameter) early in the season to maximise cell number and final fruit size. The crop loads were: high: minimally thinned to maximise competition between fruit and available assimilate; medium (control): moderate thinned to minimise competition between fruit and available assimilate; and, low: heavily thinned to eliminate competition between fruit and available assimilate.

Experimental layout was a randomised block design with 3 treatments replicated 8 times. Each plot consisted of three adjacent rows of 15 trees. The central 3 trees in each plot were used to record measurements of study variables.

**Yield and fruit quality**

Fruit maturity was determined from measurements of chlorophyll content (expressed as index of absorbance, IAD) using a portable Vis/NIR spectrophotometer (DA-meter; Model 53500, TR Turoni, Italy). To determine optimal harvest date, fruit maturity was measured on duplicate (both hemispheres) samples in situ of ~20 fruit on the control trees at weekly intervals for 4 weeks prior to harvest. At harvest (211 DABB), all fruit for each of the 3 trees per plot was handpicked. Fruit weight, number, internal quality (maturity, firmness, sweetness) and external attributes (blemish) were measured on individual fruit and sorted on a tree-by-tree (3 trees plot$^{-1}$) basis using a commercial fruit grader equipped with optical sensors (Compac InVision 9000, Compac Sorting Equipment Ltd, Australia) and a near infrared (NIR) reflectance spectrometer (Taste Technologies Ltd., New Zealand). A total of 20,667 and 1,764 plums were assessed for Tatura trellis and vase canopy configurations, respectively. Fruit-size and quality distributions were determined from data sets obtained by the commercial grading machine. Yield was calculated as the product of fruit number and weight. The NIR spectra (~30 scans fruit$^{-1}$) over the spectral range of 300-1100 nm were used to develop multivariate prediction models for sweetness, maturity and firmness. Fruit NIR reference data were collected using the conventional destructive methods with local duplicate (paired hemispheres) measures (sample size ~125 fruit) to extend model application to the experimental data. Fruit flesh firmness (kgf) was measured after exposing the flesh to a penetrometer (Model FT10, Wagner Instruments, Connecticut, USA) fitted with an 8-mm tip. Fruit juice sweetness (°Brix) was measured using a digital refractometer (Model PR-1, Atago Co., Japan). Fruit maturity (IAD) was measured using a DA-meter. Export pack-out was calculated the proportion of fruit meeting thresholds of fruit quality (fruit size, ≥70 g and sweetness, ≥12 °Brix).

**Tree growth**

Pruning biomass (winter and summer, g dry weight tree$^{-1}$), bud break and floral development stages were measured on each plot. Seasonal change of trunk cross-sectional area (TCSA, cm$^2$) was calculated from trunk circumference measures at 15 cm above the graft union on each tree within a plot during winter prior to the commencement of the crop load treatments and again in the winter dormancy after harvest. Tree size (fPAR), was measured during summer representing the period of maximum foliage cover, on a clear day using a hand-held ceptometer (Model SF80; Decagon Devices Inc., Pullman, Washington, USA) at 0930, 1230 (solar noon) and 1530 h. $f_{PAR}$ was calculated as: $f_{PAR}$ = 1-(PART/PAR), where PAR was the incident flux of PAR measured above the canopy (approximately 1.5 m above ground level in an open region within the orchard), and PART was the transmitted flux of PAR measured at the base of the canopy. Within each plot, the ceptometer was placed horizontally perpendicular to the row direction in the shaded and non-shaded area. Estimates of $f_{PAR}$ were obtained from approximately 10 and 200 ceptometer measurements above and below the canopy in each plot, respectively. Daily $f_{PAR}$ was calculated as the mean of $f_{PAR}$ at 0930, 1230 and 1530 h (Goodwin et al., 2006).

Data was subject to analysis of variance (ANOVA) using GenStat 18.1 (VSN International Limited, Oxford, UK). Significant differences between treatments were determined using Fisher's unrestricted least significant difference at P=0.05.

**RESULTS**

Table 1 presents phenology, trunk size, and tree canopy size, measured as fractional midseason daily radiation interception ($f_{PAR}$) of plum 'Angeleno' crop load treatments (high, medium, low) under two canopy systems (Tatura trellis, vase) during the 2016/17 season.

Table 1. Bloom date, trunk size and canopy size in response to crop load treatments (high, medium, low) of 'Angeleno' plum under two canopy systems (Tatura trellis, vase), Tatura, 2016/17 season.

| Treatment | Full bloom spring 2015 (DOY) | Full bloom spring 2016 (DOY) | Trunk cross-sectional area winter 2016 ($cm^2$) | Trunk cross-sectional area winter 2017 ($cm^2$) | Fractional daily radiation interception summer 2017 ($f_{PAR}$, %) |
|---|---|---|---|---|---|
| | | | Vase | | |
| High | 258 | 254 | 22 | 30 | 52 |
| Medium | 258 | 254 | 22 | 30 | 51 |
| Low | 258 | 254 | 22 | 31 | 53 |
| ANOVA | ns | ns | ns | ns | ns |
| | | | Tatura trellis | | |
| High | 258 | 252 | 26 | 32 a | 69 |
| Medium | 258 | 252 | 26 | 33 a | 67 |
| Low | 258 | 252 | 28 | 37 b | 69 |
| ANOVA | ns | ns | ns | ** | ns |

ns, *, ** and *** indicate non-significant or significant differences at P<0.05, 0.01 or 0.001, respectively, for the two-way interaction crop load treatments.

Despite having same tree density and establishment date, Tatura trellis trees exhibited larger canopies compared to free-standing vase trees due to tree architecture and tree training and associated support structures provided by wires/posts. Larger tree size under Tatura trellis was reflected in larger TCSA (winter 2016, 2017) and higher canopy radiation interception ($f_{PAR}$; 67-69 vs. 51-53%; Table 1), providing capacity to support greater fruiting levels and high yields per se (Table 2). For a given canopy architecture, fruiting level did not affect phenology (flowering: spring 2016) or canopy size (Table 1). However, trunk growth was higher on low crop load trees under Tatura trellis.

Table 2. Production parameters in response to crop load treatments (high, medium, low) of 'Angeleno' plum under two canopy systems (Tatura Trellis, Vase), Tatura, 2016/17 season.

| Treatment | Fruit number (fruit tree$^{-1}$) | Cropping level (fruit cm$^{-2}$ trunk cross-sectional area) | Yield (t ha$^{-1}$) | Fruit weight (g) | Export pack-out (%) |
|---|---|---|---|---|---|
| | | Vase | | | |
| High | 93 | 1.5 | 5.4 | 73 a | 60 |
| Medium | 75 | 1.1 | 4.3 | 78 b | 65 |
| Low | 53 | 0.8 | 3.1 | 80 b | 71 |
| ANOVA | ns | ns | ns | * | ns |
| | | Tatura trellis | | | |
| High | 423 a | 16.7 a | 46.7 a | 51 a | 10 a |
| Medium | 260 b | 10.1 b | 35.5 b | 62 b | 26 b |
| Low | 177 c | 6.4 b | 25.8 c | 66 b | 38 c |
| ANOVA | *** | *** | *** | *** | *** |

ns, *, ** and *** indicate non-significant or significant differences at *P*<0.05, 0.01 or 0.001, respectively, for the two-way interaction crop load treatments.

Table 3 shows pruning (vegetative growth) biomass for summer 2016/17 and winter 2017. No winter pruning was required under Tatura trellis compared to the vase canopy system. Irrespective of canopy system, low fruiting levels increased pruning biomass. For Tatura trellis, greater summer pruning amounts occurred in line with crop load regimes (low > medium > high). Under vase, fruit levels did not impact winter pruning of 'old wood' material, but higher current season ('new wood') biomass was measured under low crop load. Overall, seasonal (2016/17) total pruning biomass was 3- to 4-fold greater under vase compared to Tatura trellis.

Table 3. Pruning biomass (g dry weight tree$^{-1}$) in response to crop load treatments (high, medium, low) of 'Angeleno' plum under two canopy systems (Tatura trellis, vase), Tatura, 2016/17 season.

| Treatment | New wood summer 2016/17 | Old wood winter 2017 | New wood winter 2017 | Seasonal total 2016/17 |
|---|---|---|---|---|
| | | Vase | | |
| High | 464 a | 184 | 560 a | 1,208 a |
| Medium | 507 ab | 217 | 572 a | 1,296 a |
| Low | 580 b | 236 | 711 b | 1,528 b |
| ANOVA | * | ns | ** | ** |
| | | Tatura trellis | | |
| High | 324 a | - | - | 324 a |
| Medium | 421 b | - | - | 421 b |
| Low | 513 c | - | - | 513 c |
| ANOVA | *** | - | - | *** |

ns, *, ** and *** indicate non-significant or significant differences at *P*<0.05, 0.01 or 0.001, respectively, for the two-way interaction crop load treatments.

Table 2 presents production parameters under crop load regimes for vase and Tatura trellis canopy systems. For vase, fruiting number and export pack-out percentage were not significantly different (P>0.05) for crop load treatments (high, medium, low), although smaller fruit weight was observed under high fruiting levels. For Tatura trellis, fruiting levels impacted yield, fruit weight and export pack-out, following the high-medium-low treatment trends.

Table 4 shows fruit quality performance, including uniformity metrics. For vase trees, fruit maturity (IAD) and firmness were similar across crop load treatments. Uniformity (CVs) in fruit weight, sweetness, maturity and firmness were similar irrespective of crop load treatment. However, for Tatura trellis, high cropping levels produced less mature and firmer fruit. Slight improvements in variability of fruit quality uniformity (lower CVs) occurred by reduced fruiting levels (high > medium > low) with respect to fruit weight, sweetness, maturity and firmness.

Table 4. Fruit quality performance statistics in response to crop load treatments (high, medium, low) of 'Angeleno' plum under two canopy systems (Tatura trellis, vase), Tatura, 2016/17 season. Data in parenthesis represents coefficient of variation (%).

| Treatment | Fruit weight (g) | Fruit sweetness (°Brix) | Fruit maturity (IAD value) | Fruit firmness (kgf) |
|---|---|---|---|---|
| | | Vase | | |
| High | 73 (28) a | 17.3 (11) | 1.3 (11) | 3.0 (15) |
| Medium | 79 (26) b | 17.5 (10) | 1.3 (10) | 3.0 (14) |
| Low | 80 (26) b | 17.2 (10) | 1.3 (10) | 3.0 (13) |
| ANOVA | * | ns | ns | ns |
| | | Tatura trellis | | |
| High | 51 (30) a | 18.2 (11) | 1.2 (12) a | 3.0 (16) a |
| Medium | 62 (26) b | 18.4 (8) | 1.2 (10) b | 3.1 (14) ab |
| Low | 66 (26) b | 18.8 (9) | 1.1 (10) b | 3.0 (14) b |
| ANOVA | *** | ns | * | * |

ns, *, ** and *** indicate non-significant or significant differences at P<0.05, 0.01 or 0.001, respectively, for the two-way interaction crop load treatments.

Figure 1 presents distributions of final fruit size and sweetness under crop load treatments (high, medium, low) on Tatura trellis and vase canopies. Characterisation of fruit against thresholds of fruit quality (export standards: fruit size, ≥70 g and sweetness, ≥12 °Brix) showed high cropping levels reduced average fruit weight and/or pack-out performance compared to medium and low crop load treatments under both vase and Tatura trellis cropping systems (Table 2; Figure 1). Irrespective of canopy/cropping level, fruit sweetness was high (≥17.2 °Brix) with low variability (CVs ≤11%) (Table 4). Over half of all fruit grown on Tatura trellis exceeded 18 °Brix, compared to 34-38% produced on vase canopies (Figure 1).

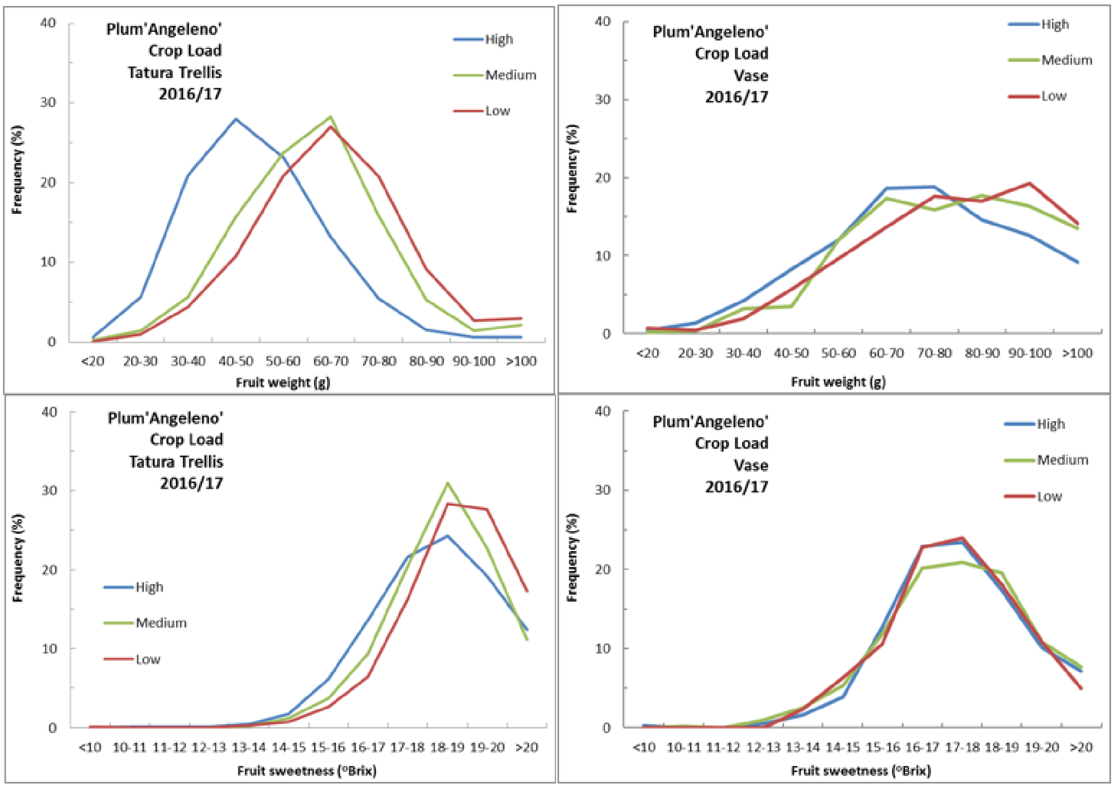


Figure 1. Distributions of final fruit weight and sweetness in response to crop load treatments (high, medium, low) of 'Angeleno' plum under two canopy systems (Tatura trellis, vase), Tatura, 2016/17 season.

## DISCUSSION

Vase produced smaller trees, lower yields and more pruning biomass compared to Tatura trellis, despite identical tree density, age and agronomic (irrigation, nutrition, pest/disease) inputs. Thinning regimes impacted the source-sink relationships to increase plum fruit size and sweetness. Low fruiting levels (sink-limited) produced large sweet fruit and more pruning biomass, irrespective of canopy architecture. For Tatura trellis, source-limitations under high crop loads resulted in poor fruit outcomes: low marketable yield due to small fruit size, low sweetness, firmer and less mature fruit. These findings suggest a delayed fruit maturation as a consequence of the increased fruit demand for assimilates under high fruit number (sink size).

Fruit composition, particularly sweetness and firmness, plays an essential role in meeting consumer expectations for flavour and taste. The tree 'ripe' harvest recommendation fruit indices for 'Black Amber' plum: sweetness 10-12 °Brix, firmness ≥1.43 kgf (Crisosto et al., 2004) were achieved under all canopy and crop load regimes (Table 4; Figure 1). However, improvements in fruit size and sweetness by reducing fruiting levels in Tatura trellis were clearly demonstrated by distribution profiles (Figure 1), production data (Table 2) and uniformity statistics (Table 4). Nevertheless, using a more stringent fruit quality metric, combining fruit size and sweetness of each individual fruit (fruit size, ≥70 g and sweetness, ≥12 °Brix), resulted in <40% of fruit grown under Tatura trellis compared to over 60% for vase trees achieving 'export class' production outcomes (Table 2).

The potential for an expansion in production of plums to meet export opportunities (e.g., China) will only be achieved if fruit, either for the fresh market or for storage, reach the customer in prime condition. As McGlasson et al. (2004) note, maximum eating quality is achieved by allowing fruit to ripen on the tree; however, as commercial harvesting occurs at an earlier stage so that the fruit are firm enough to withstand the mechanical rigours of the supply chain, fruits are effectively harvested before the maximum sweetness has been achieved. This study indicated the need for manipulation of canopy design and fruiting levels to achieve high yield, large sweet fruit, maximum pack-out of domestic/export quality fruit and minimal vegetative (pruning) growth in 'Angeleno' plums. Further, the utility of a commercial fruit grader equipped with NIR to measure every fruit to assess the agronomic response of different hand-thinning regimes on production outcomes including the distribution of fruit quality variables (size, sweetness, maturity, firmness) was invaluable.

## CONCLUSIONS

Crop load was examined to maximise uniformity in fruit quality attributes in high-density 'Angeleno' plum orchards in a temperate climate region. Results of this study support the need for thinning to ensure that plum fruit attains fresh market quality standards. The results identified canopy architecture and tree size govern photosynthetic capacity (source strength) to support an optimum fruiting level (sink size) that defines the yield limit within which the required premium quality attributes of fruit size and sweetness may be achieved. Further studies to measure within canopy effects of cropping levels and canopy architectures on fruit size, fruit quality and light interception are warranted.

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