Young apple tree responses to crop load

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Abstract

Biennial bearing is a common and important issue facing apple growers that can result in losses in production of up to 30%, depending on cultivar. To study this issue, a collaborative project focusing on molecular, biochemical and whole tree physiological responses to variable crop loads was established between German research institutions and Agriculture Victoria, Australia. The whole tree physiological component of the project was performed in the Yarra Valley in Victoria, Australia. In spring 2015, a series of crop loads, ranging from almost no fruit on the trees to double normal grower practice, were applied to the biennial bearing cultivar 'Nicoter' (Kanzi®) and to the non-biennial bearing cultivar 'Rosy Glow' (Pink Lady®). Trees were three years old, grafted on M9 EMLA rootstock and trained as Open Tatura. Several tree growth (shoot length and winter wood pruning) and productivity (fruit maturity, size, soluble solids concentration and firmness, and return bloom) factors were measured to understand the effect of crop load. Strength of the response varied depending on the cultivar and factor investigated. In general, all the measured characteristics responded to crop load with the trend inversely proportional to the number of fruit remaining on the trees. Particularly interesting was the return bloom that showed a stronger response in the non-biennial bearing Cripps Pink cultivar than the biennial bearing 'Nicoter'. This could imply that the response of young trees to thinning may be more important than the inherent tendency of the cultivar to biennial bearing.

Keywords: 'Nicoter', 'Rosy Glow', biennial bearing, return bloom, maturity, fruit quality, I_{AD} index

INTRODUCTION

The apple tree (*Malus domestica* Borkh.) is among the most important commercial fruit crops grown worldwide. Meeting market demands, while providing fruit of the highest quality, is difficult for apple producers. To achieve the optimum yield of high quality fruit, high numbers are required at fruit set, which are then thinned to the desired level. To reduce crop load, growers may remove excess fruit by hand, but, due to the cost and time required, phytochemicals which cause fruit drop are widely used, followed by a hand-thinning adjustment to optimise the fruit load (Corollaro et al., 2015).

Early fruit production before the trees have developed a complete canopy can permanently limit the final tree size and consequently, can impact future productivity. Thinning is a common agronomical practice to optimize crop load to improve fruit size and quality as well as reducing biennial bearing (Serra et al., 2016). The problem with many cultivars is alternate bearing as result of an excessive number of flower clusters and fruits (Samoulienė et al., 2016). Flower initiation is the key developmental stage for apple trees (Guitton et al., 2012), and it is inhibited by environmental conditions such as high crop load (Nichols et al., 2011), irradiance (Kittikorn et al., 2011), temperature (Kviklys and Robinson, 2010), and drought or GAs produced by seeds (Kittikorn et al., 2011).

Crop management practices and preharvest treatments influence product quality both at harvest and during storage. Crop load has been shown to affect the firmness and sensory properties of apples. Most studies have shown better quality fruit from low crop load trees

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compared to high crop-load (Corollaro et al., 2015).

An international project between Germany and Australia is underway to advance knowledge on the key molecular and physiological processes involved in the major impediments to flower bud induction which establish biennial bearing patterns. The objectives are to clarify how flowering in apple is inhibited or promoted by changes in gene expression and metabolic signals formed within the plant in response to ontogeny, plant resources, cultural practices and environmental cues. The underlying mechanisms of flower bud induction and initiation will be investigated as a 5-year study in at least two (biennial versus non-biennial) apple cultivars both in Australia and Germany. In the Australian part of the research, which is also the scope of this paper, the study focuses on the application of crop load gradient to trees in a commercial orchard setting of the biennial bearing cultivar 'Nicoter' (marketed as Kanzi®) and the non-biennial bearing cultivar 'Rosy Glow' (marketed as Pink Lady™) in the Yarra Valley, Victoria.

In this paper the effects of the first year of crop load management on vegetative growth (shoot growth, trunk cross sectional area and winter pruning dry weight), on fruit quality (size, soluble solids content, and maturity) and return bloom of both cultivars will be reported.

MATERIALS AND METHODS

The experiment was conducted in a commercial farm in Three Bridges, Yarra Valley, Victoria, Australia. Three-year-old trees of 'Nicoter' (Kanzi®) and 'Rosy Glow' (Pink Lady ®) apples, on M9 rootstock, were used. Trees were trained on open Tatura trellis, as spindles with a 4.0×1.0 m spacing. Trees were managed according to the standard local practice and commercial operations. Five crop load treatments were applied during the 2015-16 growing season with six repetitions, for a total of 30 trees per cultivar. Treatments consisted of i) 10 fruit left on the trees (0%), ii) half the standard grower practice (50%), iii) standard grower practice (100%), iv) one and half standard grower practice (150%) and v) at least double standard grower practice (200+%). Crop load treatments, as number of fruit cm^{-2} of trunk cross sectional area (TCSA), were imposed by hand thinning when fruit were around 20 mm in diameter.

Shoot growth (6 per data tree) was measured four times during the growing season. TCSA was measured 25 cm above grafting union with an electronic calliper. Pruning wood was collected during winter and dried in an air oven at 60°C till weight stabilization.

Fruit physiological age was measured as index of absorbance difference (I_{AD}) with a DA-Meter (Model 53500 T.R. Turoni, Forli, Italy), a VIS-spectrometer non-destructively measuring chlorophyll content in the fruit flesh (Ziosi et al., 2008). I_{AD} was measured on nine fruit per tree starting four weeks prior to harvest.

At harvest all fruit on the trees were counted and weighted to obtain total yield and average fruit weight (AFW). A subsample of 20 fruit was randomly selected to measure quality characteristics such as I_{AD}, flesh firmness (FF) and soluble solids concentration (SSC). Flesh firmness was determined with a food texture analyser (FTA Guss, South Africa). Soluble solids concentration was measured with a digital refractometer (Atago, Tokyo, Japan).

During next season at full bloom (80% open flowers) the number of flower clusters was counted to determine return bloom.

Treatments were applied in a randomized block design. Statistical analyses for mean separation were performed with ANOVA and Genstat 17.1 software (VSN International Limited, Oxford, UK). Regression curves were calculated and analysed with SigmaPlot 12.5 (Systat Software, San Jose, CA, USA).

RESULTS AND DISCUSSION

Tables 1 and 2 show the effects of the first season of the crop load application treatments on various vegetative growth characteristics on both cultivars. The first season of treatment application did not affect total shoot length and TCSA in any of the two cultivars, as well as winter pruning dry weight for 'Nicoter'. Pruning weight was instead affected for

'Rosy Glow' as well as the TCSA increase for both cultivars, as was similarly found by Unuk et al. (2008) on young trees of 'Golden Delicious'. When significant differences were noticeable, as expected the variable trend was inversely proportional to the number of fruit left on the trees with the least amount of growth being in the treatments with the highest amount of fruit. Significant differences were obvious between the two extreme treatments, no fruit or doubling grower practices, with the other treatments being in the middle for both cultivars. This is consistent with literature (Neilsen et al., 2001; Unuk et al., 2008).

Table 1. Vegetative growth characteristics as affected by crop load for apple 'Nicoter' during 2015-16 growing season.

Crop load (% of grower practice)	Winter pruning dry weight (g)	Shoot length end of season (cm)	Trunk cross sectional area (TSCA) season 2015-16 (cm^2)	TSCA Increase (cm^2)
0	618.2	38.3	9.6	1.67 a
50	564.8	30.9	9.0	1.30 ab
100	414.8	43.2	9.1	0.97 ab
150	363.2	43.9	8.9	0.70 b
200+	357.0	35.5	8.9	0.70 b
Significance	NS[1]	NS	NS	0.042

Values followed by different letters are significantly different (P=0.05) according to Fisher's protected LSD.

[1]Not significant at P=0.05.

Table 2. Vegetative growth characteristics as affected by crop load for apple 'Rosy Glow' during 2015-16 growing season.

Crop load (% of grower practice)	Winter pruning dry weight (g)	Shoot length end of season (cm)	Trunk cross sectional area (TSCA) season 2015-16 (cm^2)	TSCA increase (cm^2)
0	787.5 a	38.8	9.2	2.34 a
50	527.5 ab	37.6	8.9	1.79 ab
100	504.2 b	39.3	7.8	1.23 bc
150	352.7 b	37.5	8.2	0.56 c
200+	378.3 b	38.6	7.3	1.03 c
Significance	0.024	NS[1]	NS	<0.001

Values followed by different letters are significantly different (P=0.05) according to Fisher's protected LSD.

[1]Not significant at P=0.05.

Even if we did not perform statistical analyses between the two cultivars it is possible to notice that 'Rosy Glow' was affected slightly more from the crop load treatments since it had significant difference in two of the four vegetative growth characteristics considered (Tables 1 and 2). Probably due to the fact that this was the first year of crop load disruption applied, therefore cultivars compensated differently to the unbalance created by the crop load treatments (Giuliani et al., 1997; Neilsen et al., 2016; Naschitz et al., 2010; Pallas et al., 2016). Another reason, as hypothesized by Neilsen et al. (2001), could be due to the efficiency in nitrogen partitioning in the wood, which was not affected by the first season of crop load application and could be different between the cultivars under observation in our experiment. In addition, standard practice of the grower was to leave the tree tops free from fruit to stimulate extra localized vegetative growth to allow trees to fill the allotted space as fast as possible. This would support Lee et al. (2015), hypotheses on localized vigor balance at branch level. Additional research will be necessary to determine long term effects and the efficiency of the two cultivars to respond to crop load.

Our experiment was able to confirm the efficacy, efficiency and accuracy of the I_{AD} index as a practical method for growers to monitor the physiological stage of the fruit in the orchards during the growing season, as reported by Ziosi et al. (2008) and Bonora et al. (2013, 2014) for stone fruit and DeLong et al. (2016) for apples. Fruit ripening patterns during the growing season were different for the two cultivars under evaluation further confirming the cultivar specificity of the I_{AD} index (Ziosi et al., 2008; Bonora et al., 2014; DeLong et al., 2016). Figure 1 shows how accurately the I_{AD} was able to separate the effect of the crop load treatments expressed as number of fruit cm^{-2} of TCSA for both cultivars. Fruit from trees with high crop load matured more slowly in both cultivars, probably due to the lower level of photosynthates available to the fruit compared with trees with low crop load (Giuliani et al., 1997; Pallas et al., 2016). In our case there were roughly two weeks difference for the fruit at the two extremes of the crop load treatments to reach the same I_{AD} value ideal for harvesting. This shows the importance for growers to regularly monitor fruit ripening in the field to identify the optimal harvesting time (Serra et al., 2016; DeLong et al., 2016) in accordance to the preferred postharvest treatment (Prange et al., 2011) or market of choice (Stefanelli et al., 2016). It also further confirms the utility of the I_{AD} index as a method to monitor optimal fruit quality along the value chain (Stefanelli et al., 2016, 2017).

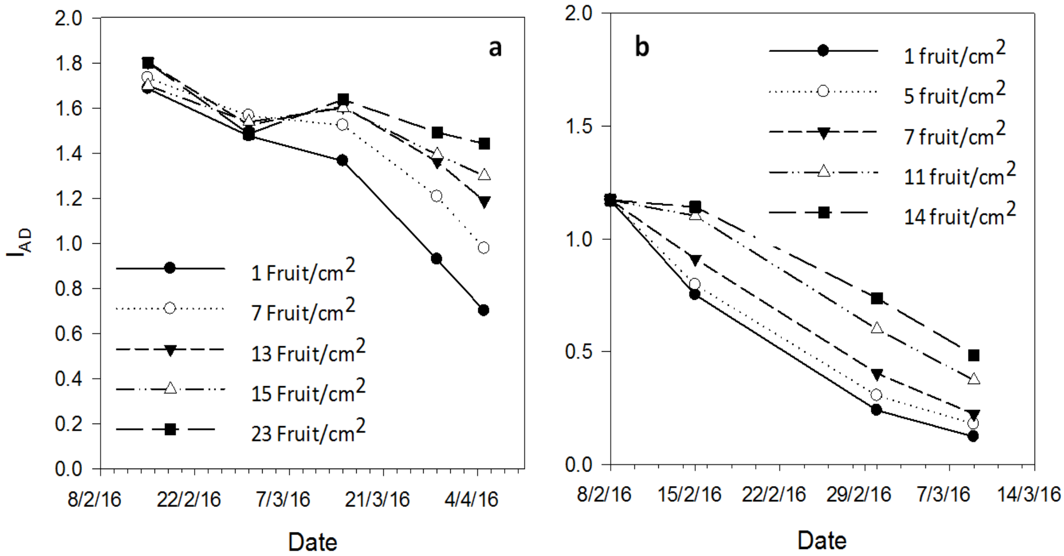

Figure 1. I_{AD} maturity index trends in the field during fruit development as affected by different crop loads (fruit cm^{-2} of trunk cross sectional area) for 'Rosy Glow' (a) and 'Nicoter' (b).

Figures 2 and 3 describe the response of AFW and SSC to crop load, expressed as number of fruit cm^{-2} of TCSA, respectively. Crop load had an effect on the fruit quality characteristics. For both cultivars average fruit weight and soluble solids concentration showed an inverse linear relationship with crop load, which reflects current knowledge (Wünsche and Ferguson, 2005; Morandi et al., 2008; Naschitz et al., 2010; Neilsen et al., 2016; Pallas et al., 2016). The variability in either AFW or SSC between the crop load extremes was higher for 'Nicoter' than for 'Rosy Glow'. There was, in fact a variation of around 120 g in fruit size in 'Nicoter' when compared to the 55 g in 'Rosy Glow' (Figure 2). A similar trend was noticed for SSC in both cultivars, as shown in Figure 3, in which 'Nicoter' had a variability of 4.2 °Brix compared to the 3.1 °Brix in 'Rosy Glow'.

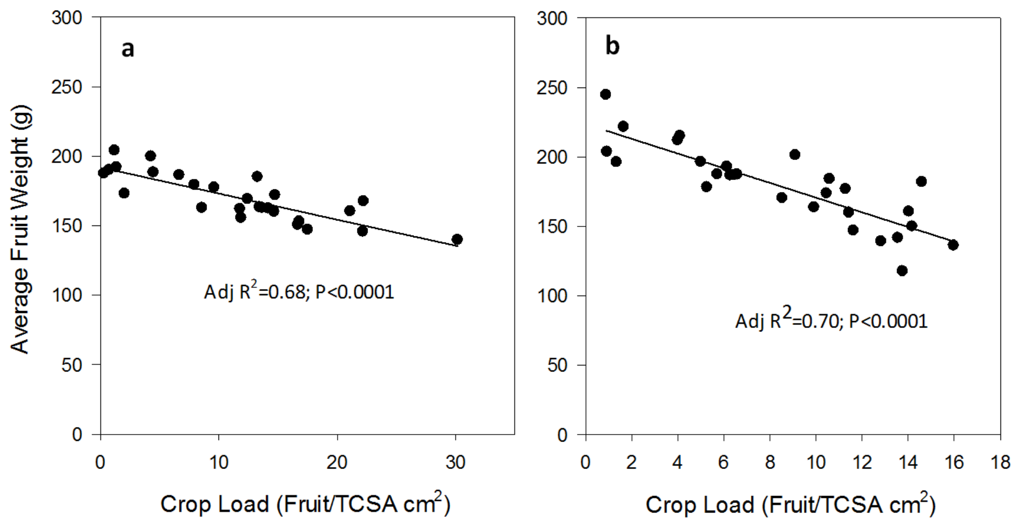

Figure 2. Average fruit weight (g) at harvest and relative linear correlation curves (n=30) as affected by different crop loads (fruit cm^{-2} of trunk cross sectional area) for 'Rosy Glow' (a) and 'Nicoter' (b).

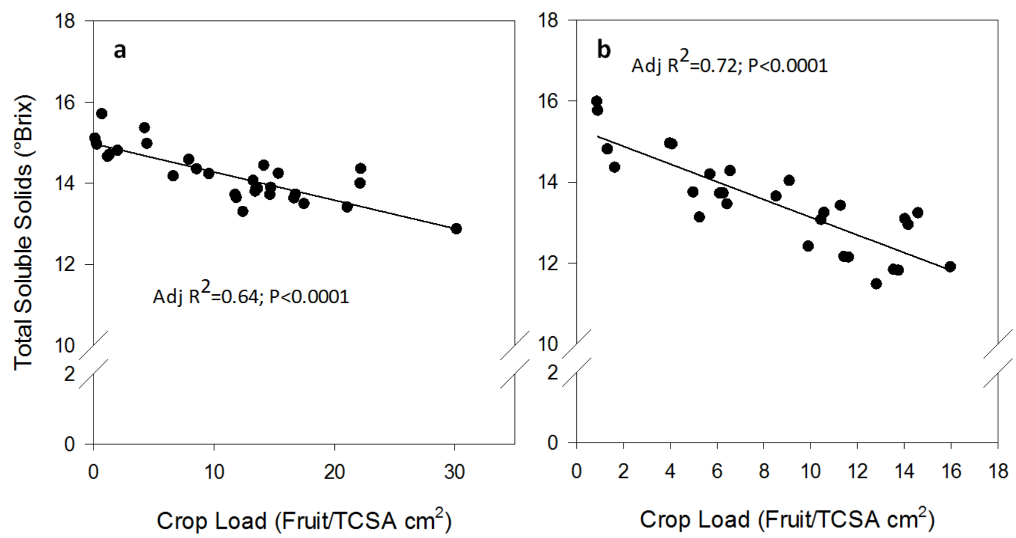

Figure 3. Fruit total soluble solids (°Brix) at harvest and relative linear correlation curves (n=30) as affected by different crop loads (fruit cm^{-2} of trunk cross sectional area) for 'Rosy Glow' (a) and 'Nicoter' (b).

The lower variability between the crop load extremes is reflected by the fact that 'Rosy Glow' seems to have a slightly lower correlation coefficient for both fruit quality characteristics, when compared with 'Nicoter', which reflects the general knowledge of Pink Lady® clones being biennial bearing neutral in comparison to Kanzi™ clones being moderately susceptible (Figures 2 and 3). It could also be that the correlations are cultivar dependent more than reflecting susceptibility to alternate bearing, in fact Neilsen et al. (2016) found a correlation coefficient of R^2=0.85 between fruit size and crop load for 'Ambrosia' with an excursion between extremes of around 200 g but did not mention and effect on alternate bearing.

One of the scopes of the project is to investigate the physiological and molecular aspects that affect alternate bearing in apple trees. We actively set-up stimulating alternate bearing through crop load management, which is recognised as one of the main inducers (Schupp, 2011). There is not much literature that considers long term effects of crop load starting from young trees, and most long-term studies do not focus on alternate bearing but other responses such as nitrogen uptake (Neilsen et al., 2001) or tree structure (Unuk et al., 2008; Lee et al., 2015). Return bloom, as an indication of possible insurgence of alternate bearing (Unuk et al., 2008; Serra et al., 2016) is, therefore, a very important aspects of our study.

Figure 4 shows return bloom responses (as number of clusters) of 'Nicoter' and 'Rosy Glow' to crop load. A strong response of both cultivars to crop load is clearly noticeable, with 'Nicoter' showing more variability than 'Rosy Glow', as previously shown for AFW and SSC. This does confirm Serra et al. (2016) findings in the known biennial bearing cultivar 'Honey Crisp' on mature trees. Unuk et al. (2008) also suggests that a strong relationship between crop load and return bloom in young trees could be an early indication of biennial bearing behaviour. It should be noted that our trees were hand thinned at around 20 mm fruit diameter and, according to Monselise and Goldschmidt (1982), at the time still early enough to overcome flower inhibition produced by young fruitlets, therefore removing time of thinning as a possible reason for the return bloom response. Our first year of findings would suggest that both 'Nicoter' and 'Rosy Glow' show a behaviour typical of alternate bearing cultivars. This goes against established thinking that Pink Lady® is biennial bearing neutral. However, most of the growers consider all clones within the Pink Lady® brand as behaving similarly. Maybe this is not the case and it may have long lasting detrimental impacts on fruit quality and the development of alternate bearing, therefore affecting long-term crop sustainability. More research will be necessary to see if 'Rosy Glow' will show alternate bearing characteristics. In our study we plan, in fact, to have a group of trees in which crop load will be adjusted to more even levels as suggested by Unuk et al. (2008), who mention that further crop load adjustments in successive years could reduce and possibly stimulate tree adjustment toward more regular bearing. Additional data collection will be required to build a correlative alternate bearing index as described by Schupp (2011).

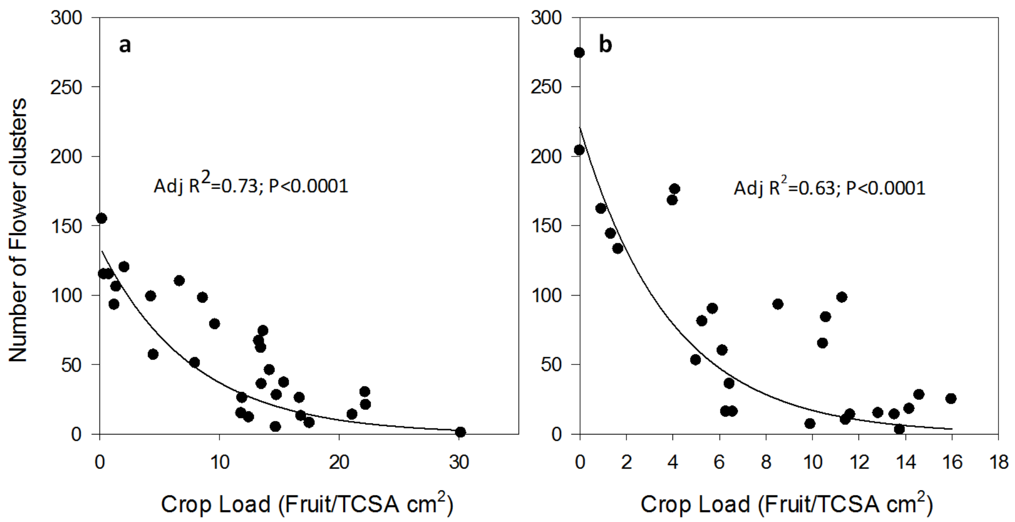

Figure 4. Return bloom as number of flowers in the following growing season and relative exponential correlation curves as affected by different crop loads (fruit cm^{-2} of trunk cross sectional area) for 'Rosy Glow' (a) and 'Nicoter' (b).

CONCLUSIONS

In our study crop load did not affect vegetative growth characteristics such as TCSA and shoot growth, while it did negatively affect TCSA increase for both cultivars under study and winter pruning dry weight only for 'Nicoter'.

A strong inverse correlation between crop load and fruit quality characteristics (average fruit weight, soluble solids concentration) and return bloom was found for both cultivars.

Fruit physiological stage development on the tree during the season was affected by crop load. Fruit from trees with higher crop load showed higher I_{AD} values, implying delayed ripening.

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