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Research article

Down-regulation of photosynthesis following girdling, but contrasting effects on fruit set and retention, in two sweet cherry cultivars

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A B S T R A C T

Sweet cherry (*Prunus avium*) trees were manipulated to analyse the contribution of soluble sugars to sink feedback down-regulation of leaf net CO_2 assimilation rate (A_{net}) and fruit set and quality attributes. Total soluble sugar concentration and A_{net} were measured in the morning on fully expanded leaves of girdled branches in two sweet cherry cultivars, 'Kordia' and 'Sylvia' characterised typically by low and high crop load, respectively. Leaves on girdled trees had higher soluble sugar concentrations and reduced A_{net} than leaves on non-girdled trees. Moreover, RuBP carboxylation capacity of Rubisco (V_{cmax}) and triose-phosphate utilisation (*TPU*) were repressed in the girdled treatments, despite J_{max} remaining unchanged; suggesting an impairment of photosynthetic capacity in response to the girdling treatment. Leaf A_{net} was negatively correlated to soluble sugars, suggesting a sink feedback regulatory control of photosynthesis. Although there were significantly less fruit set and retained in 'Kordia' than 'Sylvia'; girdling had contrasting effects in each cultivar. Girdling significantly increased fruit set and fruitlet retention in 'Sylvia' cultivar, but had no effect in 'Kordia' cultivar. We propose that low inherent sink demand for photoassimilates of 'Kordia' fruit could have contributed to the low fruit retention rate, since both non-girdled and girdled trees exhibited similar retention rate and that increases in foliar carbohydrates was observed above the girdle. In 'Sylvia' cultivar, the carbohydrate status may be a limiting factor for 'Sylvia' fruit, since girdling improved both fruit set and retention, and leaf soluble solids accumulation.

1. Introduction

In order to intensify sweet cherry production, a good knowledge of the physiological aspects related to fruit set and development is required. In Australia, blooming, fruit set, fruit growth, and ripening of cherry fruit occur from September to January–February on shoots that grew the previous year. The supply of adequate carbohydrate to fruit is crucial for fruit set, fruit growth, ripening, and final fruit quality (colour, size, firmness). Initial bloom and early fruit growth is dependent on re-mobilised carbohydrate reserves [1], accumulated by the tree during winter [2] when the sink demand exceeds the capacity of the tree to synthesise carbohydrates [3]. Subsequently developing fruit, compete with shoot growth for newly assimilated and accumulated carbohydrates. In sweet cherry, most assimilates are supplied by leaves on the same shoot where the fruit is attached [4]. Source–sink modification can enable a better understanding of the mechanisms controlling photosynthesis and dry-matter production and partitioning. In fruit trees such as apple [5], peach [6] and coffee [7,8], fruit load has a large effect on dry matter production and partitioning on vegetative and reproductive organ [9]. For instance, increasing fruit load in apple trees led to increases in dry matter production per unit leaf area and partitioning to fruit, but reduced fruit size, percentage fruit dry matter, dry matter partitioning to new shoot growth, thickening of existing woody tissue and root growth [5]. The partitioning of dry matter among various groups of organs depends on the number of organs per group and on their sink strength, i.e. their competitive ability to attract assimilates [9]. At high fruit loads, there is competition for carbohydrates among fruits that strongly affects fruit size and quality [8].

Consistency of yield is a major problem in fruit production in *Prunus*, including sweet cherry (*Prunus avium*). Abscission of fruitlets is a factor that can significantly reduce yield. The causes are unclear, but environmental influences, on photoassimilate production, and limited availability of stored carbohydrates are likely

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causal factors [10]. Source–sink manipulations are commonly used to optimise yield and quality of perennial horticultural crops [11–13]. Branch girdling is traditionally used to investigate the effect of assimilate partitioning between the tree and individual branches and evaluate how carbohydrate transfer can be altered and affect tree performance [14]. Girdling often promotes flower-bud initiation, fruit set and growth, and increases yield [15–19], but reduces vegetative growth [8,14,20] and main stem girdling is often employed in commercial practice because of these benefits. Branch girdling has been reported to alter leaf characteristics by increasing leaf mass ratio and decreasing leaf net photosynthesis (A_{net}) of numerous fruit trees [5,20–30] and accumulation of carbohydrates [7,15,18,23,28,31].

Numerous studies have reported inhibitory feedback of leaf photosynthesis in response to the accumulation of leaf carbohydrate reserves [7,23,28,31]; however, the mechanisms whereby A_{net} is decreased following carbohydrate accumulation are not well understood. Accumulation of starch in the chloroplasts has been shown to lead to sharp decrease in A_{net} due to disruption of the thylakoid membranes [32]. However, the sink limitation effect on A_{net} due to an accumulation of end products is not universally observed. It has also been demonstrated that some photosynthetic genes are sugar-repressible [33,34] and that the limiting availability of inorganic phosphate (P_i) can inhibit photosynthetic rates [35,36]. Cheng et al. [37] demonstrated that decreased A_{net} in sink-limited coffee trees was rather directly related to a lower CO_2 availability as a result of lower leaf stomatal conductance (g_s) and stomatal closure.

In view of the strong sink strength of fruits, especially during maturation, information is needed to evaluate the effect of foliar carbohydrate accumulation on sweet cherry leaf photosynthesis and fruit size. Sweet cherry is unique among temperate deciduous tree fruits in the short time elapsing between bloom and harvest (60–70 days in Southern Australia). Tasmania produces almost 35% of the Australia cherry crop, with exports accounting for over 50% of the national export. Although the cultivars most frequently grown in the region are considered to be well adapted to the local environment, there have been few field studies on carbohydrate requirements, which can impact on horticultural performance. The effects of sink-limitation were evaluated in high- and low-crop-load bearing commercial trees of ‘Sylvia’ and ‘Kordia’. The main objective of this research was to determine the influence of decreased sink demand on photosynthesis and foliar carbohydrate production. Girdling of branches offered a convenient system for the study of decreased sink demand as it interrupts the movement of photosynthates produced by leaves through the phloem.

2. Results

2.1. Photosynthetic response

We evaluated photosynthesis and biochemical parameters to determine if the cultivar and/or girdling treatment had affected overall photosynthetic capacity of fully expanded leaves of sweet cherry trees. A_{net}, g_s, and C_i, showed seasonal variation ($P < 0.001$; Fig. 1a, b and d), with substantial increase throughout spring (Nov to early Dec), and a decrease in autumn (Mar) as photoperiod and temperature decreased. In contrast, A/g_s decreased throughout the pre-harvest period and increased post-harvest (Fig. 1c). Decrease in gas exchange in autumn, or six weeks following the harvest, was larger in the ‘Kordia’ cultivar than in ‘Sylvia’ ($P < 0.001$; Fig. 1).

Branch girdling reduced significantly A_{net} (−10.4%), and g_s (−21.3%), compared to non-girdled trees irrespective of the cultivar ($P < 0.05$; Fig. 1a and b). As a result of larger decrease in g_s, A/g_s was significantly higher in girdled trees (63.1 μmol mol^{-1}) than in non-

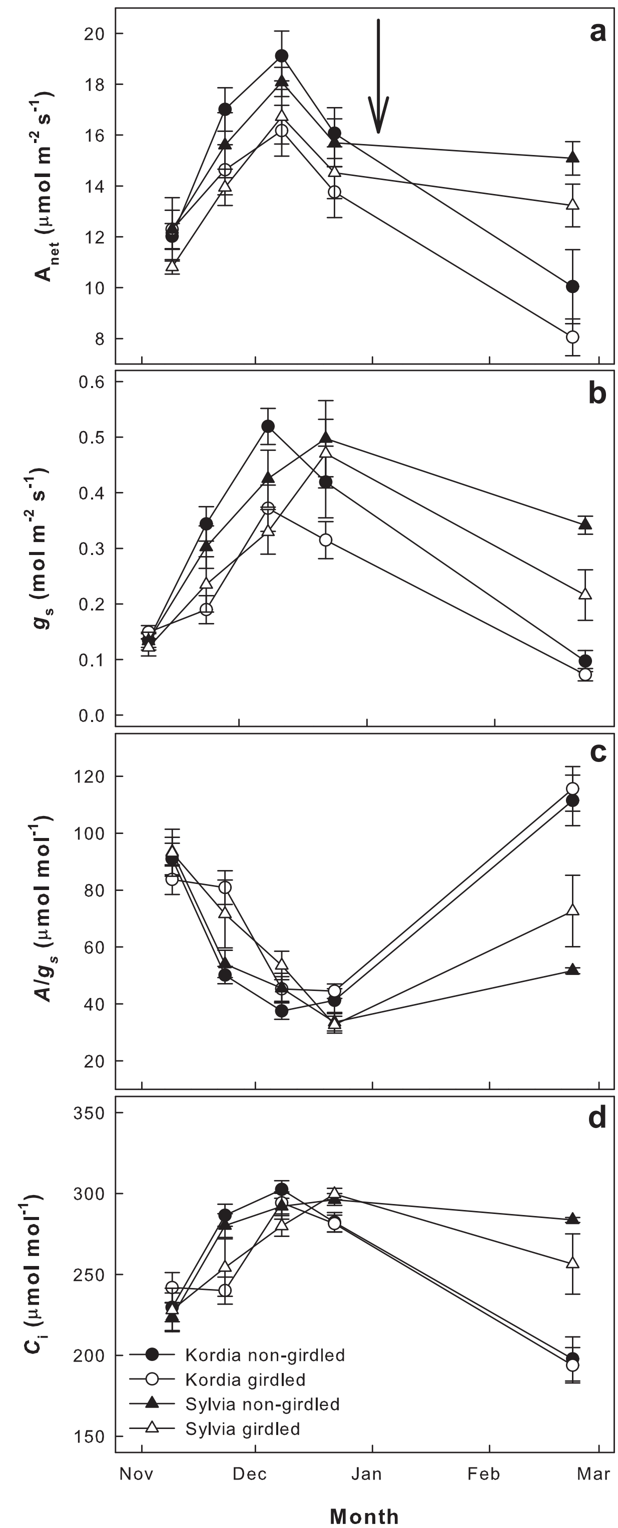

Fig. 1. Mean (±SE) on seasonal variation of net photosynthetic rate (A_{net}), stomatal conductance (g_s), A/g_s ratio, and sub-stomatal CO_2 concentration (C_i) in leaves of non-girdled and girdled fruiting branches of two sweet cherry cultivars varying in crop load: ‘Kordia’ (low cropping) and ‘Sylvia’ (high cropping) during the season 2011/2012. For each measuring time, points represent the mean of fifteen trees. The arrow indicates the time of the harvest. Gas exchange reduced significantly in response to girdling ($P < 0.05$); but the effect differed between cultivar with no effect in ‘Sylvia’.