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Reduction of apple tree height (*Malus domestica* Borkh) cv. Ultra Red Gala/MM111 does not decrease fruit yield and quality

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ABSTRACT

In Chile, like in other countries, a high percentage of apple (*Malus domestica* Borkh) orchards are grafted on vigorous or semi-vigorous rootstocks. The need to decrease the amount of labor involved and increase efficiency has motivated this study on the effect of reducing the height of cv. Ultra Red Gala/MM111 trees in a commercial orchard in the Maule Region of Chile. Apple trees were planted in 2003, and their tree heights were adjusted to 2.5, 3.0 and 3.6 m prior to blooming in 2006. The reduction of plant height from 3.6 m to 2.5 m determined a significant reduction in canopy volume (26% and 29% in 2007/2008 and 2008/2009, respectively), but no differences were detected in leaf area index (LAI) and the photosynthetic active radiation (PAR) transmitted through the canopy. However, a higher proportion of the canopies of the shorter trees had over 30% of incident PAR, the threshold for the production of good fruit quality and flower-bud differentiation. There were no differences in fruit production among plant heights, accumulating 131 tonnes ha^{-1} in the three growing seasons. Over the three seasons, the shortest plants (2.5 m) required 19, 57 and 42% less labor time at harvest, respectively, than the plants maintained at a height of 3.6 m. There were no evident differences in fruit quality among the treatments; flesh firmness varied between 73.0 and 74.0 N, soluble solids between 11.6 and 12.6°Brix, mean weight between 180 and 200 g, and the percentage of red coloring exceeded 59% of the Premium fruit in the three growing seasons. Our results suggest that it is possible to manage plants with reduced height on semi-vigorous rootstocks and thus reduce the time necessary for harvesting, without affecting fruit yield and quality.

1. Introduction

World production of apples (*Malus domestica* Borkh) is close to 65 million tonnes, with a surface area under cultivation of 4.8 million ha (Belrose Inc., 2009; FAO, 2009). Production in Chile is about 1.3 million tonnes, distributed over 35 thousand ha (ODEPA-CIREN, 2009). A high percentage of orchards is based on vigorous or semi-vigorous rootstocks. Some 70% of the plants produced in nurseries in Chile is on MM106 or more vigorous rootstocks (Sotomayor and Castro, 2004). In New Zealand, approximately 80% of orchards is planted in densities of less than 900 plants per ha (Tustin and Palmer, 2008). The use of tall trees results in lower labor efficiency (harvest, pruning, and thinning) and a higher use of agro-chemicals per hectare.

The trend in recent decades has been toward early production, with small plants and high productive efficiency. The rapid development of the canopy, with high levels of light interception and an adequate distribution among all of the plants, together with a correct balance between vegetative growth and the quantity of fruit, are necessary features to obtain a good level of precocity and high yields of good quality (Palmer and Warrington, 2000; Robinson, 2003). One of the main strategies has been the use of dwarfing rootstocks at high plant density (Sansavini, 2009). However, these rootstocks are characterized by presenting low vegetative growth (Seleznyova et al., 2008), with a poor response to fertilization (Ernani et al., 2008; Neilsen et al., 2009). Consequently, a greater number of plants per ha and an adequate support system are required, which increases the cost to establish the orchard.

Another strategy to control the size of apple plants has been the use of growth regulators, girdling or increasing the fruit load. The use of growth regulators, such as triazole (Fletcher et al., 2000) and calcium prohexadione (Medjdoub et al., 2004; Greene, 2008) has been evaluated, however, there is concern about the effects of residues on human health and the environment (Fletcher et al., 2000). Girdling the trunk can also help reduce vegetative growth, but it tends to reduce the calcium content in the fruit, increasing the risk of post-harvest physiological disorders (Goren et al., 2004).

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It is hypothesized that the efficiency of harvesting work in apple orchards based on vigorous or semi-vigorous rootstocks can be increased by reducing the size of the plant through pruning and management of the canopy, without affecting yield and quality of the fruit. There are a few reports on the effect of plant height on fruit yield and quality in apple orchards. Wagenmakers and Callesen (1989) and Callesen and Wagenmakers (1989) found in Holland and Denmark that fruit yield increased as tree height increased from 1.5 to 2.25 m. However, the smaller trees were more efficient in terms of fruit yield per tree volume (Callesen and Wagenmakers, 1989). In another study in Denmark, Callesen (1993) reported an optimal tree height of 2.75–3.25 m.

In this work, we studied the effect of reducing plant height on yield, fruit quality, vegetative growth and labor efficiency at harvest, using cv. Ultra Red Gala grafted on semi-vigorous MM 111 rootstocks in the successive three years (from 2006/2007 to 2008/2009), which correspond to the fourth to the sixth growing season after planting (in 2003). The experiment was conducted at a commercial orchard in the Maule Region of Chile.

2. Materials and methods

2.1. Experimental site

The trial was carried out in a commercial orchard of cv. Ultra Red Gala/MM111 apples planted in 2003, in the Maule Region of Chile (35° 30′ S and 71° 28′ W) over three growing seasons, from 2006/2007 to 2008/2009. The climate is a Mediterranean type, with a mean maximum temperature of 30.3 °C in the warmest month (January) and a mean minimum temperature of 3.5 °C in the coldest month (July) and a mean annual rainfall of 700 mm, with a six-month dry period.Plant material and design

The orchard was planted in 2003, with planting distances of 4 m × 2 m and solaxe training. At the time of establishing the study, the plants had reached a height of 3.8–4 m. Immediately before full bloom in 2006, the trees were topped, establishing their definitive heights at 2.5, 3.0 and 3.6 m, and maintained at these heights during the following seasons by winter pruning. The topping was performed just above a lateral producing branch. In the second and third growing seasons, the canopy was managed to leave as much as possible the same number of self-supporting branches in all treatments, in a helicoidally distribution along the trunk. In the third year, competitive branches and vigorous shoots were eliminated and the longest branches were shortened.

The trial was carried out in a complete random design with three replicates per treatment; plot size was a 720 m^2 with 10 plants distributed in two rows. Evaluations were conducted in four of the ten trees per plot, eliminating those used for leaf area measurement in the previous season.

2.3. Vegetative variables and PAR transmitted

The trunk cross-sectional area (TCSA) was measured at the beginning and end of each season. Branch cross-sectional area (BCSA), the number of branches and the terminal shoot length of the main branches in all the trees were evaluated at the beginning and end of the second and third seasons.

In the second season (2007/2008), photosynthetic active radiation (PAR) distributed through the canopy at midday was measured just before harvest (February 8th), with an Accupar LP-80 ceptometer (Decagon Devices, Pullman, WA, USA) at three heights of the canopy. Additionally, in the second and third seasons after harvest the total PAR transmitted through the canopy was measured at ground level (at 0 m, 0.5 m and 1 m on both sides of the trunk). All measurements were conducted at midday in four trees per plot and per treatment.

Leaf area per plant was determined in one tree per plot; plants were defoliated and a sub-sample of 400 g of fresh leaves was taken for leaf area determination with a LI-COR LI-3100 (LI-COR Biosciences, Lincoln, NE, USA).

Plant height and spread area were determined in four trees per plot at the end of the growing seasons. A rectangular shape was assumed for canopy volume. Following leaf fall in the 2008/2009 season, shoot number ≤30 cm and >30 cm were counted. The material removed by pruning was weighed and classified in a similar manner to determining shoot number.

2.4. Productive variables

Fruit yield per plant was evaluated by harvesting all the fruit from the trees and weighing each fruit individually. The apples were classified according to weight in ten categories, based on the number of fruit necessary to fill a box of 18.2 kg (Table 1). The harvesting time required per tree was determined each season with one plant per replication. Red coloring and the incidence of sunburn were determined visually for all the fruit. Soluble solids were determined with an Atago ATC-1 refractometer (Itabashi-ku, Tokyo, Japan) and flesh firmness using a GÜSS fruit texture analyzer (Strand, South Africa). All measurements were based on 24 fruit per treatment.

The statistical analysis was carried out with SAS/STAT 9.2 software using the GLM procedure. The Kruskal–Wallis procedure and Tukey test were used for fruit color and sunburn, with a significance of $P < 0.05$.

3. Results

3.1. Vegetative variables and PAR transmitted

The reduction of plant height from 3.6 m to 2.5 m had no effect on TCSA or $\sum$BCSA/TCSA ratios, but significantly reduced canopy volume by 26% and 29% in 2007/2008 and 2008/2009, respectively (Table 2). The number of branches per plant was adjusted to similar ranges for all treatments. However, in the second season the 3.0-m-high trees had a higher number of branches, which was corrected the following season (Table 2). The reduction in plant height did not affect the total number of buds and shoots ≤30 cm or >30 cm, averaging 454, 356 and 98, respectively. The weight of material removed by pruning in the third season (2.9 kg per tree; data not shown) was also unaffected by plant height. The LAI and the percentage of total PAR transmitted through the canopy were similar for the three tree heights in both seasons (Table 2). The PAR distribution within the canopy was also similar in the three treatments (Fig. 1A and B; Table 3), but the shorter trees presented a higher proportion of their canopies with incident PAR greater than 30%.

Table 1
Fruit count size (No. of fruit in 18.2 kg box^{-1}) and corresponding weights.

Fruit count size		60	70	80	90	100	110	120	135	150	160
Fruit weight (g)	Upper limit	400.0	269.9	239.9	217.9	193.9	171.9	153.9	137.9	125.9	117.0
	Lower limit	270	240	218	194	172	154	138	126	118	60