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Root and aerial growth in early-maturing peach trees under two crop load treatments

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Abstract

The objectives of the paper were to study the pattern of root growth (measured by minirhizotrons) in relation to trunk, fruit and shoot growth and the effects of crop load on tree growth and yield in peach trees. Two crop load (commercial and low) treatments were applied in a mature early-maturing peach tree orchard growing in Mediterranean conditions. Root growth dynamics were measured using minirhizotrons during one growing season. Shoot, trunk and fruit growth were also measured. At harvest, all fruits were weighed, counted and sized. Roots grew throughout the year but at lower rates during the active fruit growth phase. Root growth was asynchronous with shoot growth, while root and trunk growth rates were highest after harvest, when the canopy was big enough to allocate the photo-assimilates to organs that would ensure the following season's yield. Shoot and fruit growth was greater in the low crop load treatment and was accompanied by a non-significant increase in root growth. High level of fruit thinning decreased the current yield but the fruits were more marketable because of their greater size.

Additional keywords: fruit growth; minirhizotrons; phenology; *Prunus persica* L. Batsch; root length density; vegetative growth

Abbreviations used: ETc (crop evapotranspiration); RLD (root length density); ψ_{stem} (stem water potential)

Authors' contributions: Conceived and designed the experiments: JV and MCRS. Performed the experiments and analysed the data: IA, WC, LLM. Wrote the paper: IA, JV and MCRS.

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Introduction

Peach fruit yield and quality depend on environmental factors, especially water supply, and, in areas with scarce water resources, deficit irrigation strategies (application of water below full crop water requirements) are strongly recommended. The application of regulated deficit irrigation requires an accurate knowledge of the critical phenological periods during which the sensitivity of plants to water stress is maximal (Girona *et al.*, 2005; Ruiz-Sánchez *et al.*, 2010; Vera *et al.*, 2013). However, the availability of carbohydrate resources also limits reproductive growth and, thus, it has been reported that carbohydrate distribution within the tree – fruit number and position (thinning), vegetative growth and tree configuration (pruning) – affect peach yield (DeJong, 1999; Naor *et al.*, 1999; López *et al.*, 2006). Studies on carbon allocation (the process of distribution of carbon within the plant to different plant parts) reveal

the importance of root and aboveground processes to whole-plant physiology and plant productivity (Kozolowski, 1992; Dickson & Isenbrands, 1993). The differential sink capacities of the different organs of the plant follow a hierarchy established by Kramer & Kozolowski (1979): fruits > young leaves and stem tips > mature leaves > cambium > roots > storage tissues.

In deciduous trees, the initial growth of reproductive and vegetative organs depends on the mobilization of carbohydrate stores in roots (Kozolowski, 1992), and individual fruits compete with other fruits and with vegetative growth for resources (DeJong *et al.*, 1987). Besides the continual changes that occur naturally in the above-below ground ratio during tree growth, the ratio is also affected by managing fruit load and consequently the extent of the fruit sink. In this sense, several studies have revealed that crop load affects the segregation of carbohydrates, early ripening cultivars being more

sensitive to an excessive load than late maturing ones and therefore requiring more intense thinning (Pavel & DeJong, 1993; Miranda & Royo, 2002). Reductions in the number of fruits have been related with increased growth of the root system (Marsal *et al.*, 2003; López *et al.*, 2008).

Among vegetative parts of the tree, the root system is the organ responsible for water and nutrient absorption. Root studies under field conditions are labour intensive and the destructive methods involved make repeated measurements at the same site virtually impossible (Böhm, 1979; Ruiz-Sánchez *et al.*, 2005). Recent studies describe the use of ground-penetrating radar (GPR) as a non-invasive means for field root investigations, although the technique is limited to coarse roots (Guo *et al.*, 2013). Apart from these, the minirhizotron technique, which uses a miniature video camera or a scanner to view and record root images through a transparent tube inserted in the soil, is less destructive than coring and enables time-course changes in root growth to be monitored (Upchurch & Ritchie, 1983; McMichael & Taylor, 1987; Smit *et al.*, 2000; Hendricks *et al.*, 2006). This methodology has been widely applied to the study of root dynamics in annual plants (Machado *et al.*, 2003; Yang *et al.*, 2003), forest trees (Day *et al.*, 2006) and fruit trees (Fernández *et al.*, 1992; Abrisqueta *et al.*, 1994, 2008; Wells *et al.*, 2002; Bernier & Robitaille, 2004), as well as for measuring root production and mortality in several tree species (Comas *et al.*, 2000; Crocker *et al.*, 2003), but has been little used for evaluating the response to different crop management practices.

The phenological stages of the aerial parts of young early-maturing peach trees in a Mediterranean climate have been described by Mounzer *et al.* (2008). Furthermore, deficit irrigation has been shown to reduce root growth in the same peach cultivar (Abrisqueta *et al.*, 2008). The aim of this paper was to study the seasonal pattern of root growth (measured by minirhizotrons) in relation to other plant organs (trunk, fruit and shoot) to test trade-offs between vegetative and reproductive growth in a drip-irrigated adult early-maturing peach tree orchard during one growing season. Also, the effect of thinning practices (commercial and low crop load) on tree growth and yield was studied under non-limiting irrigation conditions to enlighten the interactions between root and aerial growth.

Material and methods

Experimental site conditions

The study was performed at the CEBAS-CSIC experimental station in Santomera, Murcia, Spain (38°06'N, 1°02'W, 110 m altitude). The soil, classified

as Lithic xeric haploxeroll, is stony and shallow, with a clay-loam texture. It has high lime content (50%) and very low organic matter content (0.34%), low cationic exchange capacity and low levels of available potassium and phosphorus. The available soil water content was 140 mm/m and bulk density was 1560 kg/m³. Volumetric soil water content at field capacity and wilting point were 0.29 and 0.15 m³/m³, respectively.

The climate in the region is semiarid Mediterranean, with hot and dry summers. Annual evaporation and rainfall, measured by an automatic weather station located at the orchard, were 1218 and 357 mm, respectively for the experimental period.

Plant material and crop load treatments

The plant material consisted of a 0.8 ha plot adult early-maturing peach trees (*Prunus persica* (L.) Batsch cv. Flordastar) grafted on GF-677 peach rootstock, trained to an open-centre canopy and spaced 5 × 5 m, with an average ground cover of 78%. Crop management (including pest control) was that commonly used in commercial orchards. Seasonal fertilizer applications were 200, 75, and 140 kg/ha of N, P₂O₅, and K₂O, respectively, applied through the drip irrigation system (Vera & De la Peña, 1994). The soil was kept free of weeds and was not tilled, while the peach trees were pruned annually during the dormancy period (≈15 kg of dry matter per tree), hand-thinned in March, and harvested in the first week of May.

Trees were irrigated to replace 100% of crop evapotranspiration (ET_c) requirements, using one lateral pipe per tree row, with eight 2 L/h emitters per tree. Crop evapotranspiration was estimated by multiplying daily reference evapotranspiration (ET₀), calculated using the Penman-Monteith method (Allen *et al.*, 1998), by the crop coefficient (Abrisqueta *et al.*, 2013). Irrigation was scheduled weekly and the water was applied daily during the night as needed. The annual amount of water applied, measured with in-line water meters with digital output pulses (ARAD), was 770 mm.

At the time of thinning, in March 2010, two fruit crop load treatments were established: a commercial crop load (fruitlets were hand-thinned to leave approximately 20 cm between the fruits) and a low crop load (approx. one fruit per 40 cm), with no effect on leaf area. Crop load treatments were arranged in a completely randomized design with four replicates, each consisting of one row of 5 trees.

Root measurements

Root growth was evaluated using the minirhizotron method. For this, transparent plastic tubes were installed

at a 45° angle, 50 cm from the second emitter (located 1 m from the tree trunk) (Fig. 1a), in one representative tree in three out of the four replications in both crop load treatments. The tubes were 1.8 m long with outer and inner diameters of 70 and 64 mm, respectively. The total length of each buried tube was 1.4 m, so that it reached a total depth of 1 m; the centre of each tube was located directly beneath the emitter (Fig. 1a). The part of the tube protruding from the soil surface was covered with isolating material to prevent light from entering the tube and the tube from becoming heated. Six years after installation of the tubes, root images were captured twice per month using a CI-600 Root Growth Scanning System and analysed using WinRHIZO™ Tron software v.2008 (Regent Instruments Inc., Quebec, Canada). The number, length and diameter of roots were determined at seven depths (minirhizotron section) from 0 to 140 cm, at 20 cm intervals. Roots were classified into three diameter classes: very fine (<0.5 mm), fine (0.5–2.0 mm) and coarse (>2 mm).

Root length density (RLD) was calculated according to the formula proposed by Upchurch (1987), based on Newman's line intersection method, which uses the number of root points which intersect the minirhizotron tube within the view frame: $RLD = (N \cdot d) / (A \cdot d)$, where N is the number of roots, A is the minirhizotron frame area observed by the scanner (439.82 cm²), and d is the outside diameter of minirhizotron tube (7 cm). It calculates the expected value of root length within the soil volume occupied by the tube as if the tube were not present (Merrill & Upchurch, 1994). RLD was expressed as total root length per unit of sampled soil volume (cm of root/cm³ of soil). Two analysis procedures were compared: the first included the determination of all the roots observed in the image (total roots) and in the second, only newly grown roots, characterized by their distinctive white colour, were traced (new roots).

Soil cores (52 mm diameter; 452 cm³) were collected in July from the commercial crop load treatment only, in four trees (three of them the same as those equipped with minirhizotrons). Six successive 15 cm soil samples to a depth of 90 cm were taken at distances of 0 and 30 cm both sides from the second emitter (Fig. 1a). The samples were placed in 12 L containers filled with water and sodium hexametaphosphate (≈ 20 g per sample), which causes flocculation of the clays, in order to separate the roots from the soil. After cleaning and sieving (0.55 mm mesh), the roots were digitalised with a scanner (LA 1600+, Regent Instruments Inc., Quebec, Canada) with a resolution of 600 dpi. Images were analysed with the WinRhizo Pro™ software (Regent Instruments Inc., Quebec, Canada). Data were expressed as RLD (cm root/cm soil), considering the diameter classes indicated above.

A comparison was made between RLD data from the soil cores and the data obtained by the minirhizotron at the summer sampling date, taking into account the relative location of the minirhizotron: values from sections 2, 3, 6 and 7 of the minirhizotron were compared with soil samples at 15, 30, 75 and 90 cm depth, respectively, taken 30 cm from the emitter; while values from sections 4 and 5 were compared with soil samples at 45 and 60 cm depth, respectively, taken below the emitter (Fig. 1a).

Aboveground measurements

The equatorial fruit diameter was measured weekly from early March until harvest in 100 fruits, randomly selected from four trees (one for each replication) of each crop load treatment using an electronic digital calliper. Fruit diameter (D, mm) was converted into fruit dry weight (DW, g) using the allometric relationship derived from data collected in the same orchard ($DW = 4 \cdot 10^{-4} \cdot D^{2.54}$; $n = 190$; $r^2 = 0.90$; Mounzer *et al.*, 2008).

The shoot length was taken twice monthly, measuring four tagged shoots per tree, one from each compass direction, on four trees (one tree per replication) of each crop load treatment with a tape measure. Trunk diameter was monitored continuously with linear variable displacement transducers (model DF ±2.5 mm, accuracy ±10 μm, Solartron Metrology, Bognor Regis, UK) attached to the trunk. Measurements were taken every 2 s and the datalogger (model CR10X with AM25T multiplexer, Campbell Scientific, Logan, UT, USA) was programmed to report 15 min means. Growth rates for root, shoot, trunk and fruit were expressed as increases in length or weight per day.

Stem water potential (Ψ_{stem}) was determined using a pressure chamber (Soil Moisture Equip. Crop. Model 3000, Santa Barbara, CA, USA) on mature leaves located on the north face of the tree near the trunk. Leaves were placed in plastic bags covered with aluminium foil for at least 2 h prior to the measurements, which were carried out at midday every 7–15 days from April to October. One leaf per tree and one tree per replication of each crop load treatment was cut and immediately placed into the chamber following the recommendations of Hsiao (1990).

Peach yield was evaluated at harvest during the first week of May in two picks, weighing and counting the total number of fruits per tree, in twenty trees per crop load treatment (five trees from each replication). Peach fruits were divided in the field by manual calibration into 5 fruit diameter categories (<56, 56–61, 61–67 and 67–73 and >73 mm) and all the fruits of each category were weighed on a field scale. According to Commission Regulation Directive 1221/2008 (EC, 2008), 56 mm is

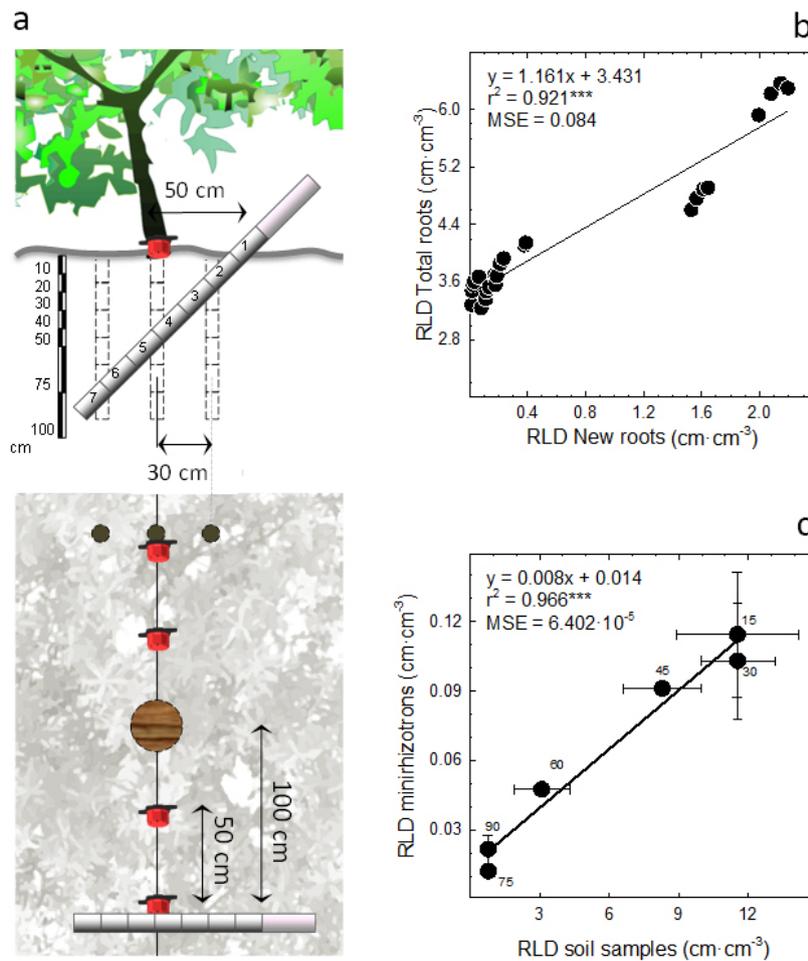


Figure 1. Relative location of minirhizotron tube and soil core samples obtained in July, with respect to peach tree trunk (red points indicate the emitters) (a). Relationship between early-maturing peach root length density (RLD) data evaluated as total roots and new roots in the commercial crop load treatment. Each point is the average of three replications (b). Relationship between RLD data obtained by minirhizotrons and soil samples, in the commercial crop load treatment. Numbers on data points correspond to soil depth (cm). Bars on data points are \pm standard error of the mean ($n=3$, for minirhizotrons) ($n=4$ for soil sampling) (c).

the minimum diameter for a peach fruit to be considered in the “Extra class”. Total soluble solids were evaluated in a 10 fruit sample of each replication and treatment on each picking date, using a hand-held refractometer (Atago ATC-1, Tokyo, Japan). Values were expressed as °Brix.

Statistical analysis

Plant growth data were analysed by a general linear model of repeated measures ANOVA using SPSS v. 20 software (SPSS, 2012), which considers the within-subject factor as a series of measurements taken in the same experimental subject over time (root, shoot and

fruit growth) and the between-subject factor (crop load treatment). Regression analysis was performed for the methodological procedures used to obtain root data.

Results

Methodological procedures using minirhizotrons

The root images captured from minirhizotrons were analysed with two procedures: total roots (all the roots in the image were traced) and new roots (only newly grown white roots were traced). The comparison made between RLD data (including all diameters classes)

from the commercial crop load trees calculated by the two analysis procedures showed good correlation, with a significant coefficient ($r = 0.96^{***}$) (Fig. 1b).

The results of the comparison made between RLD data from the soil cores and the data obtained by the minirhizotron at the summer sampling date revealed a high correlation and a clear tendency for the minirhizotron to underestimate RLD data (1:100 ratio) compared to the RLD obtained for the soil samples (Figure 1c). Peach root length density through the soil profile was similarly described by both methods, with maximum root exploration located above 45 cm (Fig. 1c).

Root vs. aerial peach growth pattern

The annual growth pattern of the different organs (roots, fruits, shoots and trunk) of peach trees from the commercial crop load treatment is showed in Fig 2. Root length data included all diameters [in general, most roots (88%) corresponded to very fine roots (<0.5 mm), 7 and 5% for fine and coarse roots, respectively]. Data were expressed as percentage of the total growth at the end of the season (Fig. 2b) and as daily growth rates (Fig. 2c), both graphs showing alternating dynamics between aerial part (shoots and fruits) and roots. Crop evapotranspiration (ETc) is also included to depict seasonal peach tree water consumption, with maximum ETc values observed after harvest, but decreasing from September onwards (Fig. 2a).

Root growth rates increased immediately after harvest, with a peak at mid-summer. A slight increase was observed just before dormancy (Fig. 2c). While fruits had completed their growth in early May, the roots and trunk had only completed 20% of their total growth

at this time. On the other hand, shoots had already reached more than 60% of their final development (Fig. 2b).

Low root growth rates were observed during the active growth phase of the fruits (Fig. 2c). The maximum shoot growth rate coincided with the lowest root growth (Fig. 2c). Trunk growth followed the same pattern as the roots, with maximum growth occurring during the postharvest period (Fig. 2c).

Crop load and peach tree growth

The plant water status was unaffected by the crop load, and similar values of Ψ_{stem} were observed in commercial and low crop load treatments, varying by around -0.30 and -0.45 MPa, during stages II and III of the fruit growth periods, respectively (data not shown). Trees were irrigated to satisfy their water needs and hence the soil water content in both crop load treatments, as measured by capacitance probes, remained on average at about 0.28 m³/m³ (around field capacity values) during the season (data not shown).

Differences were observed in fruit growth, the peaches of the commercial crop load treatment were significantly ($p < 0.05$) smaller than those of the low crop load treatment at stage III of fruit growth (Fig. 3a). The growth of lateral shoots was also seen to be affected by the crop load, and higher shoot length values were measured in the trees with a low crop load compared with those of the commercial load treatment, although this effect was only statistically significant after fruits were harvested (Fig. 3b).

Root growth was enhanced in the low crop load treatment (Fig. 3c), with the most active root growth period, as indicated above, occurring after harvest; however, according to the ANOVA, this effect was not

Table 1. Effect of crop load on yield and fruit size distribution of early-maturing peach trees

	Commercial crop load	Low crop load	Significance ^[2]
Yield (kg/tree)			
1 st pick	12.7	10.1	ns
2 nd pick	14.6	5.4	*
Total	27.3	15.6	*
Total number of fruits/tree	205	109	*
Average fruit weight (g)	133	144	*
Size distribution (% for each diameter class) ^[1]			
< 56 mm	3.96	1.16	*
56-61 mm	11.25	7.31	ns
61-67 mm	42.00	31.97	ns
67-73 mm	36.38	40.88	ns
> 73 mm	6.41	18.68	*

^[1]Mean values of 1st and 2nd picks. Percentage values were arcsine-transformed before statistical analysis. ^[2] * $p < 0.05$; ns= non-significant

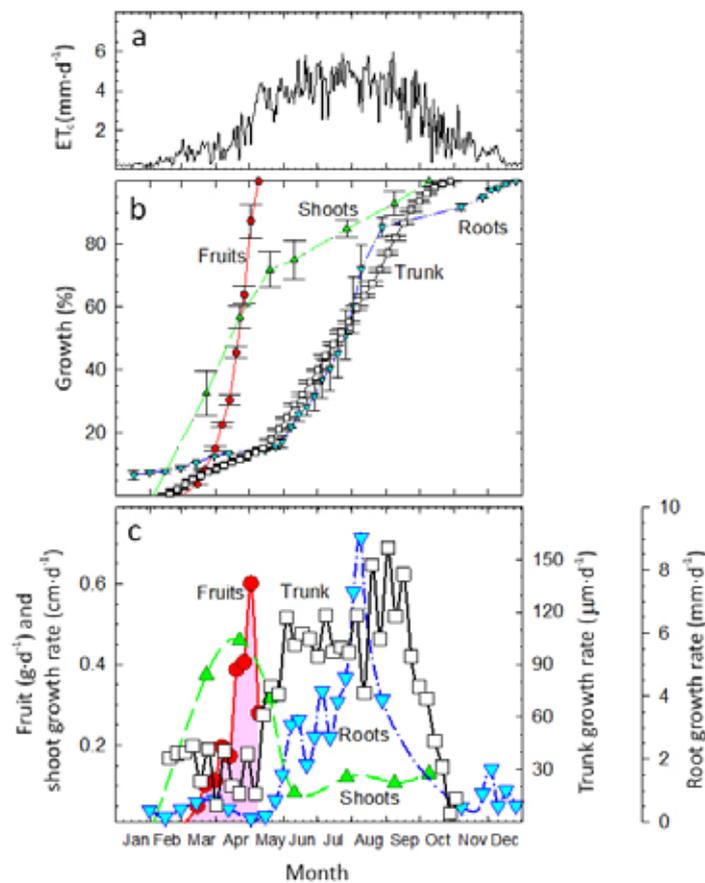


Figure 2. Crop evapotranspiration (ET_c) (a). Seasonal evolution of fruit weight (\bullet), shoot length (\blacktriangle), trunk diameter (\square) and root length (\blacktriangledown) of early-maturing peach trees under well irrigated commercial crop load treatment, expressed as percentage of the annual growth (b) and as daily growth rate, increase in length or weight per day (c). Bars on data points are \pm standard error of the mean of four (fruits, trunk and shoots) and three (roots) replications.

statistically significant ($p = 0.39$). Root growth through the soil profile showed that this increase mainly affected the 30-60 cm soil layer (Fig. 3c').

Peach total yield was lower ($p < 0.001$) in trees subjected to low crop load conditions than the trees with a commercial crop load due to the lower number of fruits collected in the second pick (Table 1). Nevertheless, the average fruit size was significantly higher in trees of the low crop load treatment (Table 1), with more than 90% of the harvested fruits corresponding to commercial size (>61 mm diameter), compared to 84% in the commercial crop load. The ANOVA of the size distribution provided statistically significant values for fruits of <56 mm diameter (1 and 4% for low and commercial crop load treatments, respectively), while the opposite was found for fruits of >73 mm diameter (19 and 6% for low and commercial crop load treatments, respectively) (Table 1). The crop load had a significant effect ($p = 0.02$) on total soluble solids (TSS) of fruits from the first pick (6.65 and 7.87 °Brix for commercial and low crop

load treatments, respectively), while higher ($p < 0.001$) values were recorded in fruits harvested in the second pick (10.5 and 10.9 °Brix for commercial and low crop load treatments, respectively).

Discussion

Methodological procedures using minirhizotrons

The minirhizotron technique was designed for demographic studies and to evaluate root growth dynamics (Taylor, 1987; Comas *et al.*, 2000; Hendricks *et al.*, 2006; Krasowski *et al.*, 2010), providing a unique method to repeatedly measure root segment growth over time. WinRHIZO-Tron® requires the roots to be manually traced by the operator, the good correlation obtained between total and new roots (Fig. 1b) demonstrated that the method of simply tracing the new roots is a more practical approach to the evaluation

of peach root dynamics in the field, since data can be obtained more quickly, speeding up the analysis.

Many authors consider that minirhizotron and soil sampling provide different evaluations of standing root length in field conditions due to the heterogeneous distribution of roots and the effect of collecting soil vertically, which will provide different values to those obtained at an angle of 45° (Johnson *et al.*, 2001; Milchunas, 2009). Nevertheless, it is worth recalling that the root system of fruit trees under drip irrigation, especially those in semi-arid zones such as in the Mediterranean area, is practically restricted to the wetted zone of the soil, with most root activity concentrated just below the emitters (Fernández *et al.*, 1992; Ruiz-Sánchez *et al.*, 2005; Pérez-Pastor *et al.*, 2014). As regard the effectiveness of using minirhizotrons to study peach root distribution, the results of both methods revealed a high degree of correlation ($r=0.97^{***}$, Fig. 1c) but there was a clear tendency for the minirhizotron to underestimate RLD data compared with the data obtained from soil samples. This underestimation was related to the conditions at the tube interface, which may inhibit roots as they come up against the surface of the minirhizotron (Upchurch, 1987; Rytter & Rytter, 2012). Similar discrepancies in absolute root length values between soil sampling and minirhizotron methods were found in almond (Franco & Abrisqueta, 1997) and maize (Majdi *et al.*, 1992). Nevertheless, leaving aside any comparison of absolute values, the soil exploration profile of peach roots was similarly described by both methods, with maximum RLD values at 15-45 cm soil depth (Fig. 1c), suggesting that minirhizotrons can be used for studies on root dynamics and morphology (Rytter & Rytter, 2012).

Root vs. aerial peach growth patterns

Tree phenology can be defined by temporal dynamics of organ growth, an accurate knowledge of which is essential for designing crop management practices such as irrigation, thinning and pruning. Growth pattern of the peach roots, fruits, shoots and trunk showed a clear alternating dynamics between aerial (shoots and fruits) and root parts (Fig. 2).

Coinciding with low water demand conditions (Fig. 2a), the root growth rate was lower during the active growth phase of the fruits (Fig. 2b), which act as powerful photo-assimilate sinks. Analogous behaviour has been observed in other deciduous fruit species such as almond (Ross & Catlin, 1978) and apricot (Pérez-Pastor *et al.*, 2004) and in perennials, such as citrus trees (Bevington & Castle, 1985). Also, a decrease in root production was related to the presence of growing fruits in late-maturing peach trees (Williamson &

Coston, 1989) and walnut trees, whose roots followed a unimodal seasonal curve (Contador *et al.*, 2015). Also, the maximum peach shoot growth rate coincided with the minimum of root growth (Fig. 2c). One or two peaks in the annual root growth of apple trees have been reported to occur at different times, depending on the scion/rootstock combination, but always asynchronous with the peaks of shoot growth (Ma *et al.*, 2013). Similarly, avocado root growth was slower during shoot growth flushes (Mickelbart *et al.*, 2012).

Shoot growth in mature trees is fairly independent of the distribution of carbon during the growing season, once the initial elongation has ceased (Sprugel *et al.*, 1991), although some researchers have suggested that this autonomy is not total (Marsal *et al.*, 2003). In this sense, Chalmers & van den Ende (1975) indicated that the growth of the fruit, roots and frame is competitively inter-related throughout the life of the peach tree, while the growth of leaves and the annual shoots that support them is independent.

Although carbohydrates were not measured in this study, a possible role for carbohydrate use/storage related to plant phenology might be inferred, as Comas *et al.* (2005) suggested for the intricate relationship between internal carbon demands and environmental conditions in regulating vine root allocation. Thus, peach root and trunk growth increased once harvesting was completed and the canopy was big enough to distribute the photo-assimilates to organs that would ensure a successful yield the following season.

On the other hand, it was observed that peach root growth continued during the whole year (Fig. 2), demonstrating that both soil temperature and humidity were favourable. This suggests that roots were not dormant in the sense that buds were, underlying the importance of monitoring root growth between the growing seasons as well (Rytter & Rytter, 2012).

Crop load and peach tree growth

The early maturing nature of the studied peach cultivar and the adequate water supply, as indicated by the high soil water content values in both crop load treatments, may have been responsible for the absence of significant differences in plant water status, reflecting the results obtained by Naor *et al.* (1999), Conejero *et al.* (2010) and Alcobendas *et al.* (2012), who reported no differences in Ψ_{stem} values even between extreme crop load treatments (unthinned and defruited). In this sense, too, Berman & DeJong (1996) indicated that in well-watered peach trees, plant water status was independent of crop load, while in trees receiving reduced irrigation, the degree of water stress increased with increasing crop load, water-stressed trees with heavy crop loads

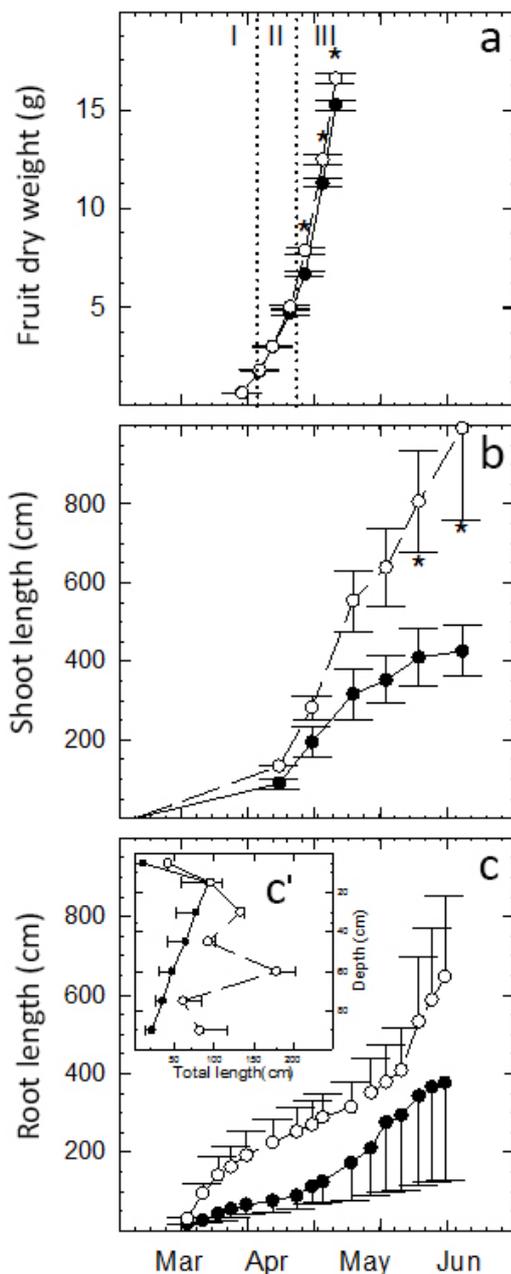


Figure 3. Seasonal growth of fruit dry weight (a), shoot length (b) and total root length in 0-100 cm soil profile (c), and through soil profile in July (c') of early-maturing peach trees in commercial (closed symbol-solid line) and low (open symbol-dashed line) crop load treatments. Bars on data points are \pm standard error of the mean of four (fruits and shoots) and three (roots) replications.

making significantly greater demands, thus limiting photosynthesis.

It is commonly assumed that reductions in crop load increase the total amount of carbohydrates available for the growth of other organs (Wardlaw, 1990; Grossman & DeJong, 1995; Marsal *et al.*, 2003). The higher peach tree growth under low crop load conditions

compared with trees with a commercial load (Fig. 3) was probably due to increased competition for photo-assimilates among fruit themselves and, also, between the fruit and other organs that were developing at the same time (Grossman & DeJong, 1994). High cropping peach trees generally have reduced vegetative growth (Berman & DeJong, 2003) and root growth (Chalmers & Van den Ende, 1975). Results in support of this were found in experiments with late-maturing peach trees in both potted (López *et al.*, 2008) and field grown (Ben Mimoun & DeJong, 2006) conditions, in which root growth was significantly higher in defruited than in commercial crop load treatments. Nii (1993) reported that the total root volume of non-bearing peach trees was larger and the starch content per root dry weight higher than in bearing trees.

Changes in vegetative growth could have major implications as regards a plant's ability to cope with soil water deficits. The negative effects of water stress on fruit could be partially compensated by more severe fruit thinning, as previously reported for mid-late maturing peach cultivars in Mediterranean regions (Marsal *et al.*, 2006; López *et al.*, 2010). However, no improvement in fruit size in low loaded early-maturing peach trees was observed under deficit irrigation conditions (Alcobendas *et al.*, 2012).

Peach yield, although considered low in the year described (Vera *et al.*, 2013), was lower in trees subjected to low crop load conditions than in the trees with a commercial crop load due to the lower number of fruits (about half the number of the commercial crop load) (Table 1). Nevertheless, peach fruit size improved in low crop load trees (Table 1), showing similar levels of soluble solids to the commercial loaded trees. Thus, the low crop load enhanced marketability because size is one of the most important quality criteria. Mahhou *et al.* (2006) reported a negative relationship between crop load and fruit size in late-maturing peach trees. This relationship also was influenced by the cultivar, early-maturing cultivars being more sensitive to excess load than late-maturing cultivars (Pavel & DeJong, 1993; Alcobendas *et al.*, 2012). Fruit farmers might be interested in adopting high thinning practices (low crop load treatment) when market demands favour larger fruits.

It is clear that in areas with scarce water resources, deficit irrigation strategies are strongly recommended, and its application requires an accurate knowledge of the critical phenological periods during which the sensitivity of plants to water stress is maximal. Thus, understanding the relationship between vegetative and reproductive growth provides insight into the timely relationships among growth events and should help growers to adopt the best cultural practices:

e.g. irrigating, fertilizing, spraying and pruning. The literature describes the stage II of fruit growth in medium- and late-maturing cultivars, and the post-harvest period as the most suitable for reducing irrigation in peach trees (Ruiz-Sánchez *et al.*, 2010); however, deficit irrigation strategies should be adjusted to limit water deficits during the exceedingly long post-harvest period for early-maturing peach cultivars (Vera *et al.*, 2013).

On the other hand, crop load management to partially alleviate the effects of water deficit has been considered a useful technique, which interacts with deficit irrigation to decide carbon allocation within the tree (López *et al.*, 2006; Mirás-Avalos *et al.*, 2013). Thinning practices in deficit irrigated peach trees should be adapted to the actual tree size (especially shoot length), but leaving a certain distribution to ensure their exposure to sunlight.

In conclusion, the evaluation of the growth of new roots is proposed for studying peach root dynamics using minirhizotrons. The seasonal growth of roots of early-maturing peach trees was asynchronous with that of shoots. Root growth continued throughout the season, with lower rates during the active fruit growth phase. Root and trunk growth rates increased immediately after harvest when the canopy was big enough to destine the photo-assimilates to organs that would ensure the following season's yield.

Trees with a low crop load showed more active shoot and fruit growth than commercial crop-loaded trees, a non-significant increase in root growth being noted in the low crop load treatment. Low crop loads led to a lower total yield, although individual fruit size was larger, which might increase profits if the market demands larger fruit. Such a change in tree architecture might have major implications for the plant as regard its ability to cope with soil water deficits.

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