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Effects of Thinning and Pruning on Shoot and Fruit Growths of Girdled Fruit-bearing Shoots in Two Peach Tree Cultivars ('Big Top' and 'Alexandra')

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Summary

Shoot and fruit growths were investigated in two peach cultivars, a medium maturing ('Big Top') and an early maturing ('Alexandra'). Experiments were achieved on fruit-bearing shoots (FBS) isolated from the tree by girdling, thinned to one or three fruits and with a steady number of shoots. This shoot growth was either maintained free or stopped by removing their apical bud. The girdled FBS were located on trees subjected to two thinning ('Big Top') and three pruning ('Alexandra') treatments. On the girdled FBS, increasing the number of fruits, on the one hand, and stopping shoots growth, on the other hand, stimulated shoot and fruit growths, respectively. These results show that fruit growth does not limit shoot growth but at the opposite contributes to improve it, and that available assimilates are preferentially oriented to shoot growth over fruit growth. By contrast, on the whole tree, shoot growth was found limited under a higher fruit load. A higher fruit load also limited fruit growth and soluble solids content on the whole tree, in similar proportions than those of the girdled FBS. Compared to light pruning, severe pruning induced higher shoot and fruit growths on the whole tree and on the girdled FBS. Fruit growth and quality at maturity are shown highly dependant on the leaf-to-fruit ratio which vary with thinning and pruning intensities.

Key words. Fruit weight – girdling – *Prunus persica* – soluble solids – vegetative growth

Introduction

An adequate control of fruit growth is required in commercial orchards to ensure the economic profitability of the horticultural farming. Various experiments have reported that assimilates supplies provide fruit growth and total soluble solids in kiwifruit (Buwalda et al. 1990), apple (Avery et al. 1979), or peach (Crews et al. 1975). Partitioning of available assimilates inside a tree is hence determinant for the elaboration of fruit growth and quality (Forshey and Elfving 1989), and this partitioning highly depends on the relationships between the different organs of the tree (Marini and Sowers 1994; Walcroft et al. 2002; Farina et al. 2006).

In a peach tree, the relationship between vegetative and fruit growths has not been totally elucidated. According to experimental results obtained with a late maturing peach cultivar, available assimilates appeared to be preferentially oriented to shoot growth over fruit growth (Genard et al. 1998). However, for a late maturing peach cultivar, vegetative growth precedes fruit growth, so that assimilates transport is naturally oriented to shoot over fruit. For a medium or an early maturing peach cultivar, fruit and vegetative growths take place at the same time, so that the fruit demand in assimilates is more likely to compete with the shoot demand, possibly leading to varying partitioning of the assimilates between fruit and shoot. Further experiments have to be performed with different peach cultivars to better assess vegetative and fruit growths connections.

In peach, transport of assimilates can occur over relatively long distances and among different branches (Chalmers and Van Den Ende 1975a; Roper et al. 1987). In order to prevent these long distance transports of assimilates so that studying fruit and shoot growths evolution in their vicinity, girdling has to be achieved to isolate fruit-bearing shoots (FBS) from the rest of the tree (Ben Mimoun et al. 1996). Relationship between vegetative and reproductive growths could be then directly assessed on girdled FBS with making their leaf-to-fruit ratio vary. At the level of the whole tree, assessing different thinning and pruning severities under a constant number of FBS and fruits, respectively, are two methods that are likely to make the leaf-to-shoot ratio of the whole tree vary.

In this study, we investigated shoot and fruit growths on FBS isolated from the tree by girdling, with different numbers of fruits and leaves in order to assess varying leaf-to-fruit ratios on these FBS. These girdled FBS were situated on trees subjected to different thinning or pruning severities as making leaf-to-fruit ratio vary on the whole tree. Experiments were achieved on two peach cul-

tivars: 'Big Top', a medium maturing cultivar, and 'Alexandra', an early maturing cultivar.

Materials and Methods

The study was carried out in two peach tree orchards (cv. 'Big Top' and 'Alexandra' on GF 305 rootstock) planted in 1996 and 1998, respectively; and fruit ripening dates were around 20 July with 'Big Top' and 25 June with 'Alexandra'. The orchards were situated at the Gotheron Experimental Station near Valence in the Middle Rhône Valley in France. The soil was stony alluvial with 15 % clay, 30 % silt and 54 % sand, considered particularly suitable for peach tree cropping (Bornand 1968). Each of the two plantations was composed of three rows of 21 trees: the trees were planted 4.5 m apart between the rows, and 2 m apart within the rows. The number of main scaffold branches per tree was two (Y training according to Clauzel et al. 1986). All the trees received routine horticultural care except for thinning and pruning, which varied according to the treatments. The two experiments were performed on the middle tree rows (Fig. 1), the external rows being taken as guard rows. The homogeneity of the experimental areas had been maintained by sowing cereal crops for three successive years before planting, and had been checked by measuring tree trunk circumferences before the application of the treatments.

The experiments were performed during years 1999, 2000 ('Big Top') and 2002 ('Alexandra'). For 'Big Top', only the results obtained in 1999 are presented; they were confirmed in 2000. Each of the two thinning ('Big Top') or three pruning ('Alexandra') treatments were arranged in five blocks (Fig. 1). For 'Big Top', total fruit load on the whole tree was maintained low, with 80 fruits (80 FR), or high, with 240 fruits (240 FR). For 'Alexandra', pruning severity on the whole tree was light, with 120 FBS kept on the tree, medium with 90 FBS, or high with 60 FBS; the total number of fruits was maintained constant (270 FR). Severe pruning usually enhance the shoot growth (Marini 1985; Bussi et al. 2005); therefore, the leaf-to-fruit ratio on the whole tree was expected to increase under the higher intensities of thinning and pruning.

The exchange of assimilates between some FBS and the whole tree was prevented by completely girdling the base of these FBS at the end of April for 'Big Top' and at the beginning of May for 'Alexandra', i.e. 45–55 days after full bloom. A 50 mm wide strip of bark was removed from the base of the FBS, and the girdles were checked periodically throughout the experiments to prevent reconnection of the phloem. The FBS to be girdled were sampled at the periphery of the canopy at the same height from the ground and similarly orientated for the different trees. Every experimental tree had two ('Big Top') or four ('Alexandra') girdled FBS, so that the experimental design for each cultivar could be assimilated to a split-plot with a first plot corresponding to the whole tree and a second one to the girdled FBS (Fig. 2).

The girdled FBS were thinned to one or three fruits and their number of shoots was limited to three (Fig. 2). For 'Alexandra', these shoots were kept free or shortened so as to maintain or suppress their elongation growth, respectively. When they were shortened, their apical bud was removed and only five leaves were left on the shoots. In summary, for 'Big Top', T1 and T2 represented one fruit and three fruits on the girdled FBS, respectively; for 'Alexandra', T1, T2, T3 and T4 represented one fruit and free shoots, one fruit and shortened shoots, three fruits and free shoots and three fruits and shortened shoots, respectively (Fig. 2). These different treatments applied to the girdled FBS aimed at obtaining varying leaf-to-fruit ratios. These ratios decreased when the number of fruit increased or when the vegetative growth was suppressed.

For 'Alexandra', the shoot lengths and the cheek diameters of the peaches on the girdled FBS were measured once a week from the beginning of May, i.e. close to the application of the treatments. Moreover, on the rest of the tree, the total shoot length per FBS was evaluated on five sampled FBS. For 'Big Top', the shoot lengths on the girdled FBS and on five FBS sampled on the rest of the tree were measured twice a month from the end of April. Data collected at the first measurements were not significantly different for shoot and fruit growths (average length and diameter about 100 and 30 mm, respectively), so that their further growths were assessed from these first meas-

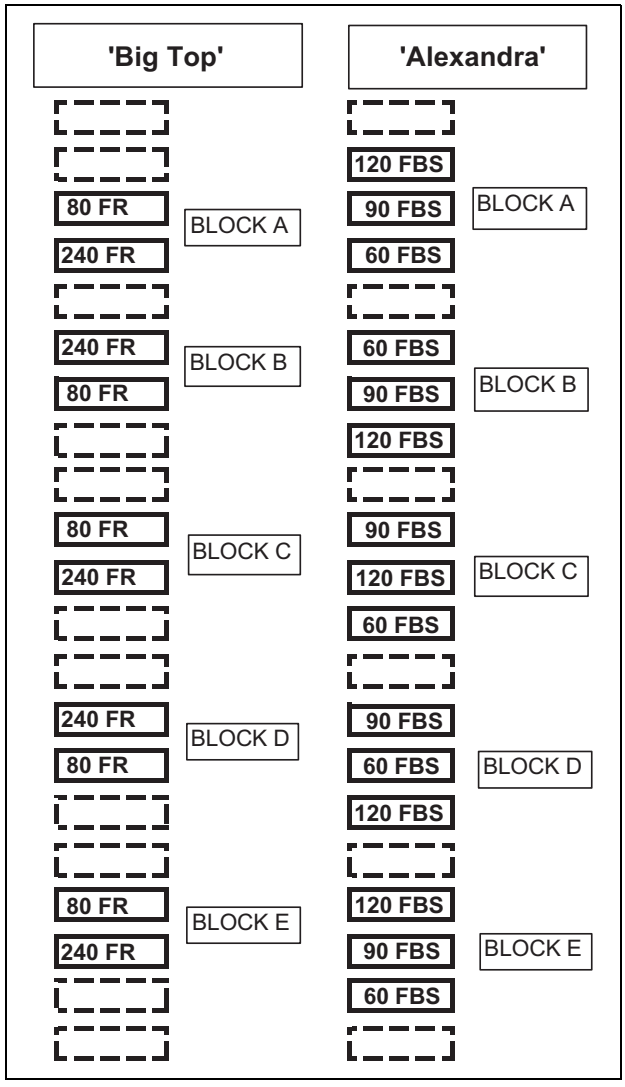


Fig. 1. Experimental layout. Each tree is represented by a rectangle (dotted for guard trees).'Big Top': 80 FR, 240 FR; 'Alexandra': 120 FBS, 90 FBS, 60 FBS (FR = fruits; FBS = fruit-bearing shoots).

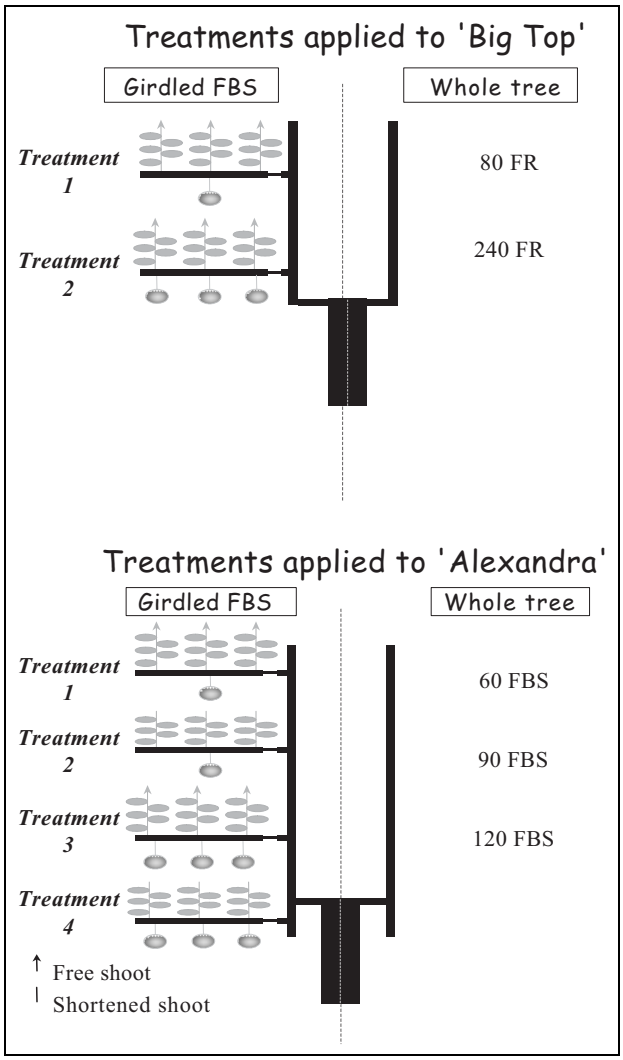


Fig. 2. Treatments applied to the girdled FBS and to the whole tree of peach trees (cv.'Big Top' and 'Alexandra'). FR = fruits; FBS = fruit-bearing shoots. See "Materials and Methods" for the legend.

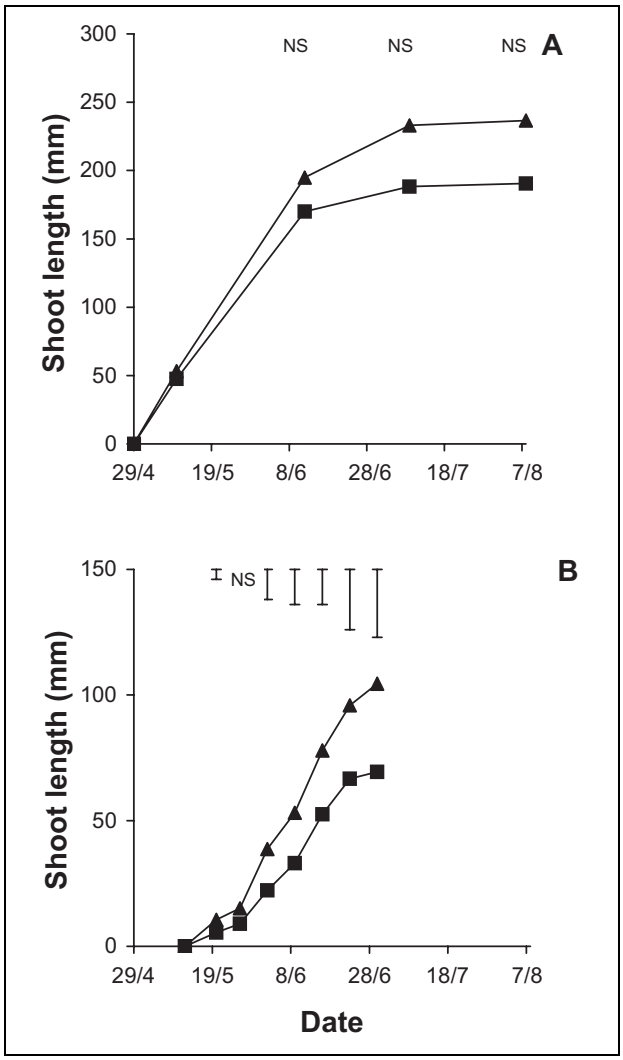


Fig. 3. Time-course of average shoot length according to the number of fruits, one (■) or three (▲), on the girdled FBS of peach trees. A: cv. 'Big Top'; B: cv. 'Alexandra'. Vertical bars denote LSD at $P \leq 0.05$; NS, not significant.

urements considered as the zero points of the experiments (see Fig. 3 to 6). For 'Alexandra', the fruits were picked when their growth curve displayed a saturation pattern. Thus, harvest was started later than under commercial conditions to better assess total fruit growth. The fruits on the girdled FBS were weighed at harvest. Soluble solids percentages, indicative of the assimilate partitioning between shoot and fruit (LESCOURRET et al. 1998), were determined in these fruits with an Atago PR-32 digital refractometer. For 'Big Top', the fruits of the five shoots sampled on the rest of the tree were also measured at harvest.

Analyses of variance were achieved (DAGNELIE 1975) at each date of measurement and at harvest using the 'Statgraphics Plus' v. 5.0 software package. No significant interaction was detected between the treatments of the whole tree and those of the girdled FBS, so that their respective results were separately presented for each cultivar. The comparison of treatments was carried out using Fisher's test, and the significant differences between treatments was identified at the 5 % probability level. The least-square difference (LSD) was performed for average discrimination.

Results and Discussion

Relationship between shoot and fruit growths on the girdled FBS

For both cultivars, the maximum shoot growth on the girdled FBS was reached at the beginning of July, and it was greater with three fruits on the girdled FBS than with a single fruit (Fig. 3). This tendency observed with the 'Big Top' cultivar was significant with 'Alexandra' (Fig. 3A and B, respectively): the vegetative growth with three fruits on the girdled FBS was 25 % and 50 % higher than that with a single fruit for 'Big Top' and 'Alexandra', respectively. These results show that fruit growth does not reduce shoot growth, but at the contrary can stimulate

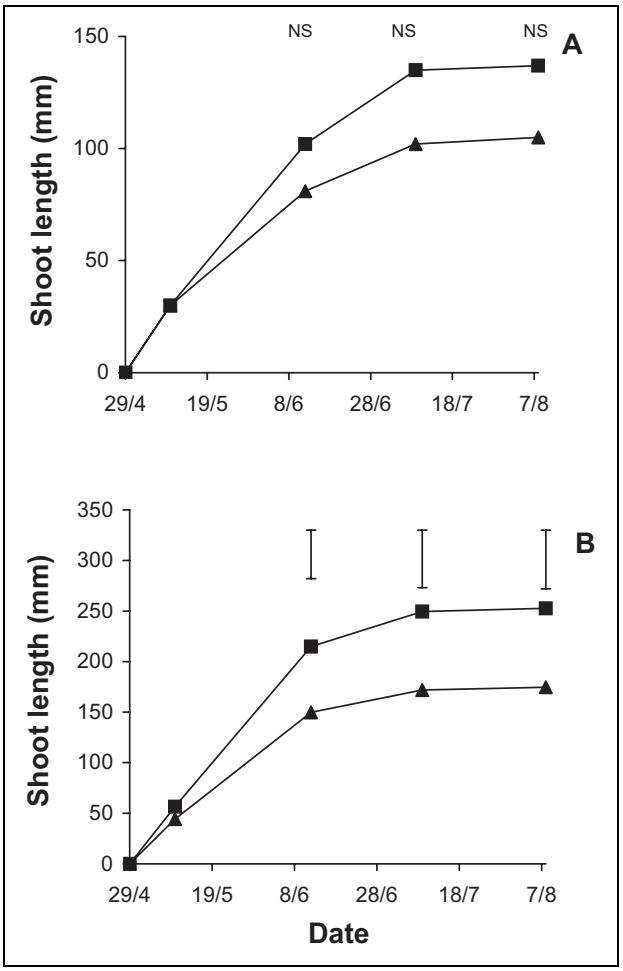


Fig. 4. Time-course of average shoot length (A: on the whole tree; B: on the girdled FBS) according to the total number of fruits in the peach tree (cv. 'Big Top'): 80 (■) or 240 FR (▲). Vertical bars denote at $P \leq 0.05$; NS, not significant.

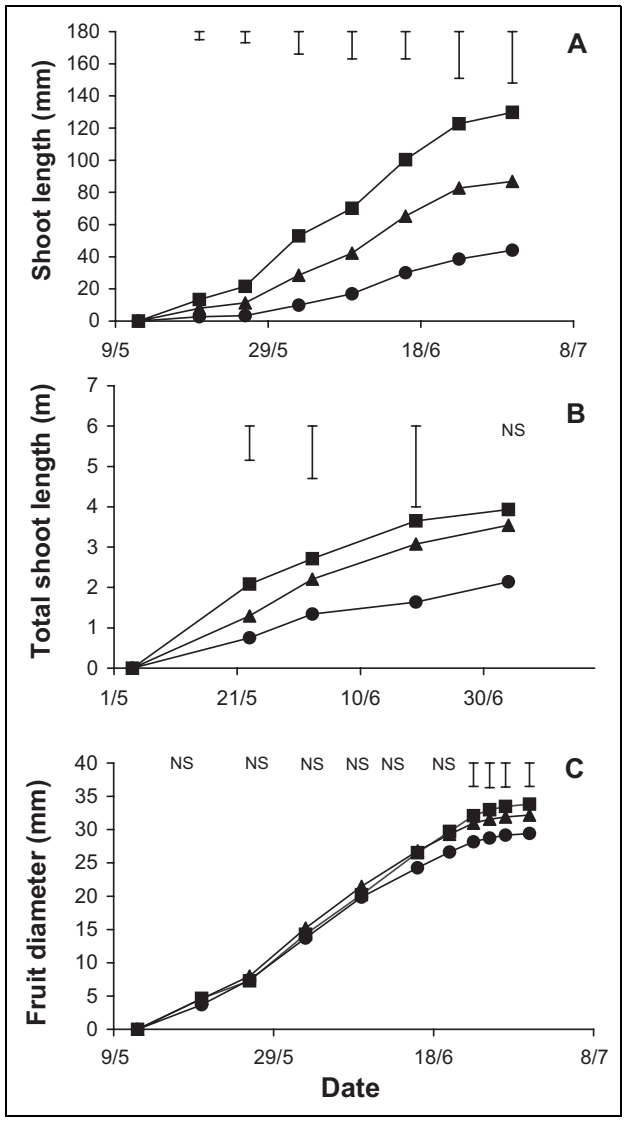


Fig. 5. Average shoot length (A), fruit diameter (C) on the girdled FBS and total shoot length per FBS (B) on the rest of the tree according to the total number of FBS on the whole peach tree (cv. 'Alexandra'): 60 (■), 90 (▲) or 120 FBS (●). Vertical bars denote maximum LSD at $P \leq 0.05$; NS, not significant.

shoot growth. To explain this stimulation, a positive effect of growing fruits on leaf photosynthetic activity can be put forward (Lescourret et al. 1998). Because of its effect of sink strength, fruit growth is likely to decrease the carbohydrate reserves of the leaves, and, as a consequence, to reduce the feedback inhibition of photosynthesis currently induced by these reserves (Ben Mimoun 1997). The lack of vegetative growth reduction under increasing fruit load with an early maturing cultivar had already been mentioned (Nicolas et al. 2006), but no stimulation had been clearly shown. The highest stimulation was detected with 'Alexandra', the earlier maturing cultivar, suggesting this effect was emphasized as fruit and vegetative growth simultaneously occurred.

Concerning the effect of growing shoot on fruit growth, the diameter of the single fruit was significantly increased with stopped shoots (T2) compared to that with free shoots (T1) until 2 June (see LSD bars in Fig. 6), suggesting that shoot growth can limit fruit growth. This effect, obtained with the early maturing cultivar, probably resulted from the limited sink strength for assimilates of the single fruit compared to the strong and simultaneous shoot sink strength (Schaffer et al. 1987; DeJong 1999). That is in accordance with the hypothesis of available assimilates to be preferentially oriented to shoot growth over fruit growth in peach (Genard et al. 1998). Nevertheless, after 2 June the diameter of the single fruit under T1 and T2 tended to be equivalent, the very slight fruit diameter differences as reaching fruit ripening had not to be taken into account because not significant. With three fruits on the girdled FBS, fruit growth under shortened shoots was only slightly higher than that under free shoots at the beginning of fruit growth, and it tended to be lower as reaching fruit maturity (T4 *versus* T3 in Fig. 6). Accordingly, the average fruit weights at harvest, as well as soluble solids percentages, tended to be lower with shortened shoots compared to those with free shoots (−5–10 % in Table 1). This trend to lower fruit diameter and soluble solids percentages at fruit maturity, induced

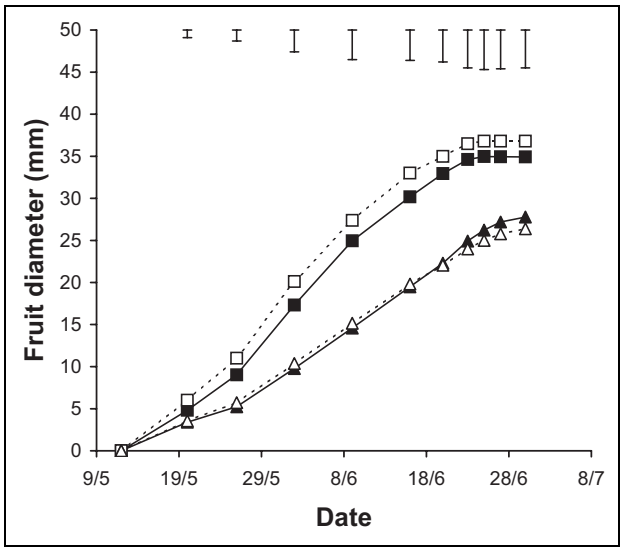


Fig. 6. Peach (cv. 'Alexandra') growth according to the number of fruits and the state of shoot growth on the girdled FBS. T1, one fruit and free shoots (■); T2, one fruit and shortened shoots (□); T3, three fruits and free shoots (▲); T4, three fruits and shortened shoots (Δ). Vertical bars denote maximum LSD at $P \leq 0.05$.

by shortened shoots compared to free shoots, is supposed to result of a decrease in available assimilates under the lower leaf-to-fruit ratio (Weinberger 1931; Dann et al. 1984; Wright 1989).

Effects of thinning and pruning on shoot and fruit growths

Fruits on the girdled FBS were smaller and contained less soluble solids than those on the rest of the tree (see Table 1), which could be attributed to an effect of late girdling, reported to induce a limitation of available assimilate into the girdled FBS (Day and DeJong 1990), combined with the number of shoots limited to three on the girdled FBS (Wu et al. 2005). Nevertheless, increases in average fruit weight and fruit soluble solids percentages were similar (+ 10–20 %) on the whole tree and on the girdled FBS when the number of fruit, in both situations, was divided by three under thinning (from 240 to 80 FR on the whole tree, from three to one fruit on the girdled FBS) (Table 1, cv. 'Big Top'). Therefore, similar variations in the leaf-to-fruit ratio on the whole tree and on the girdled FBS induce similar variations in their fruit growth and soluble solids content, confirming that the leaf-to-fruit ratio is determinant for fruit quality (Flore and Lakso 1989).

An increasing fruit load on the whole tree (from 80 to 240 FR) induced a limitation of shoot growth (Fig. 4A), also affected on the girdled FBS, i.e. 30 % lower under 240 FR than under 80 FR (Fig. 4B). This result seemed contradictory with the shoot growth stimulation under increasing fruit load on the girdled FBS as shown above, so that a competition between fruit and root growths has to be supposed for available assimilates (Bevington and Castle 1985; Williamson and Coston 1989; Volz et al. 1993). That agrees with Inglese et al. (2002) who found that C-transport from root to fruit in early-ripening peach seems particularly active in spring. The induced limitation of root growth would then contribute to the observed reduction of shoot growth in accordance with the theory of the shoot-root balance (Blasing et al. 1990; Blanco et al. 1995).

Table 1. Average fruit weights and soluble solids percentages in peach at maturity. No significant interaction was detected between the girdled fruit-bearing shoots (FBS) and the whole tree treatments, so that their respective results were separately presented for each cultivar. P value is given by Fisher's test.

Cultivar	Fruit location	Treatment	Average fruit weight (g)	Fruit soluble solids (%)
'Big Top'	Girdled FBS	T1	125.2	15.7
		T2	111.6	14.3
		P value	0.035	0.285
	Whole tree	80 FR	186.3	17.2
		240 FR	168.9	14.4
		P value	0.044	0.032
'Alexandra'	Girdled FBS	T1	106.7	10.8
		T2	105.8	10.3
		T3	85.4	8.7
		T4	76.4	7.9
		P value	0.009	0.012
	Whole tree	60 FBS	138.2	8.9
		90 FBS	132.1	8.8
		120 FBS	126.2	9.0
		P value	0.033	0.521

On the girdled FBS, for Big Top, T1 and T2 represented one fruit and three fruits, respectively; for Alexandra, T1, T2, T3 and T4 represented one fruit and three shoots, one fruit and shortened shoots, three fruits and free shoots and three fruits and shortened shoots, respectively. FR = fruits; FBS = fruit-bearing shoot.

On the girdled FBS, the shoot growth under 60 FBS by tree was three times higher than that under 120 FBS by tree (Fig. 5A). On the rest of the tree, the shoot growth per FBS was also significantly higher under severe pruning compared to that under light pruning on the first three dates of measurements (Fig. 5B). The well-known effect of shoot growth stimulation under high pruning severity was hence confirmed under our conditions (Li et al. 1994). Compared to the light pruning, fruit growth on the girdled FBS was significantly higher (+ 15 %) under the severe pruning (Fig. 5C), probably as a result of the increasing assimilates availability with shoot growth enhancement (Chalmers and Van Den Ende 1975b; Grossman and DeJong 1994).

In conclusion, on the girdled FBS, the vegetative growth was stimulated under increasing fruit load, and,

close to maturity, the fruit growth and soluble solids content evolved in the same way than did the leaf-to-fruit ratio. On the whole tree, the increasing fruit load induced, on the one hand, a lower shoot growth probably as a result of a limitation of root growth, on the other hand, a lower fruit quality in accordance with the leaf-to-fruit ratio decrease. Thinning and also pruning appear likely to modulate the assimilate partitioning between shoot, fruit and root. Further experiments including effective measurements of root growth should be performed to better evaluate the interrelations between the different organs of the tree.

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