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Effects of Centrifugal Pruning on Agronomic Performance and Fruit Quality in a Medium-Maturing Peach Cultivar

C. Bussi[1)] and D. Plenet[2)]
([1)]INRA, UE 695 Unité Expérimentale Recherches Intégrées, St. Marcel-les-Valence, France, and [2)]INRA, UR 1115 Plantes et Systèmes de Culture Horticoles, Site Agroparc, Avignon, France)

Summary

Centrifugal pruning (CentP) was compared to conventional pruning (ConvP) over a five-year period beginning in 2004 with five-year-old peach trees, of the medium-maturing cultivar 'Caprice', under the conditions prevalent in the Middle Rhone Valley in France. CentP is a new training system for peach trees designed to improve light distribution in the canopy by creating a "light well" around the scaffold through early manual pruning. CentP tended to increase total soluble solids compared to ConvP, but the average fruit weight tended to decrease under CentP. Nevertheless, because of the increase in fruit yield, notably as a result of the greater number of flowers per shoot length, the relative profitability of fruit production was higher under CentP than under ConvP. Labour demand increased under CentP compared to ConvP, in the same proportion as monetary returns, so that the supplemental costs due to this innovative pruning method tended to be economically compensated for by increased fruit production. Water sprouts were removed in spring under CentP, instead of in summer under ConvP. Because summer is considered to be the busiest time of the year for fruit producers, CentP appears to be more advantageous in terms of work time management in the peach orchard than ConvP. Brown rot incidence tended to decrease at fruit maturity and until post-harvest storage under CentP compared to ConvP. This suggests that appropriate pruning practices possibly decrease peach disease sensitivity, which could lead to the reduced use of pesticide sprays to control brown rot in the orchard.

Key words. brown rot – fruit weight – *Prunus persica* – soluble solids – work time

Introduction

Adequate control of fruit growth and quality is required in commercial orchards to ensure the economic profitability of horticultural farming. Fruit growth and quality in peach are highly dependent on the capacity of leaves (source) to supply assimilates to the fruit (sink) (Crews et al. 1975; Farina et al. 2006). These assimilate supplies were shown to depend on fruit location: first, on the fruit-bearing shoot (FBS) and, second, at the whole-tree scale (Chalmers and Van Den Ende 1975; Wu et al. 2005). An environmental factor, light transmission through the tree canopy, also appears to be crucial for improving peach tree growth, cropping and fruit quality (Flore and Lakso 1989; Dejong 1999; Walcroft et al. 2002).

Concerning fruit position on FBS, fruits close to strong carbohydrate sinks (actively growing shoots or other fruits) may be assimilate-deprived (Lai et al. 1989). On the contrary, peaches close to assimilate sources (near leaves) may be larger (Corelli-Grappadelli and Coston 1991). At the whole-tree scale, resistance to carbon transport appeared to play an important role for peach growth (Genard et al. 2008; Marsal et al. 2003). As a result, increasing the distance between source leaves and fruit sinks could limit the translocation of photosynthates from leaves to fruits in peach (Dejong and Grossman 1995; Genard et al. 1998). Therefore, methods likely to favour the proximity of leaves and fruits inside the tree should be adopted in order to improve peach quality.

Concerning the environmental factor, it has been reported that pruning affects light interception in peach trees. Notably, summer pruning was previously performed in order to eliminate the undesirable water sprouts that congest the centre of the canopy, blocking light and preventing fruit colouration (Rom and Ferree 1985; Li et al. 2003). However, the optimal period for summer pruning in peach is still subject to debate. Gordon and Dejong (2007) reported that early water sprout removal in spring could be performed to improve light interception in the centre of the canopy much earlier than under conventional water sprout removal, which usually occurs at the beginning of Stage III of peach growth, *i.e.*, around three weeks before fruit maturity (Myers 1993).

In apple, the factors mentioned above that are likely to have an impact on fruit production and quality have been taken into account in a new pruning approach known as centrifugal pruning (Willaume et al. 2004). The aim of this method is to optimise the relationship between vegetative growth and fruiting, especially by encouraging proximity between leaves and fruit at the periphery of the tree (Lauri et al. 2008). Centrifugal training also includes the management of well-lit canopies with high light porosity that favours faster carbon availability for fruit early in the season (Lakso and Corelli-Grappadelli 1992). Return bloom, fruit size and uniformity appeared to be improved in apple orchards under centrifugal training with respect to conventional training (Lauri et al. 2004). Pest incidence, notably scab, was shown to be reduced in apple orchards under centrifugal pruning, compared to conventional pruning. It was hypothesized that the microclimate created inside the canopy was less favourable to pest development (Simon et al. 2006).

A study was carried out to apply this innovative pruning method to peach tree. The principles underlying centrifugal pruning in peach also consist in increasing light porosity within the tree by removing potentially shaded fruiting laterals in winter, and water sprouts that limit light penetration inside the canopy in spring, i.e., much earlier than under conventional summer pruning (Plenet et al. 2010; Navarro and Plenet 2011). Centrifugal pruning (CentP) was compared to conventional pruning (ConvP) over a five-year period in a five-year-old medium-maturing peach tree orchard, cultivar 'Caprice', under the conditions prevalent in the Middle Rhone Valley in France. Since the adoption of an innovative pruning method depends on its ability to maintain sound agronomic performance, the effects of this pruning practice on tree growth, fruit yield and quality were assessed, in addition to labour demand in the orchard and monetary returns, to better evaluate its profitability. The effect of CentP on brown rot incidence was also tested.

Materials and Methods

Orchard description

This study was carried out in a peach tree orchard planted in 2000 at INRA's Gotheron Experimental Station near Valence in the Middle Rhone Valley in France (45.0° N; 4.9° E). The soil was stony alluvial with 15 % clay, 30 % silt and 54 % sand, considered particularly suitable for growing peach trees.

The area of the experimental orchard was 0.30 ha. 'Caprice', a medium-maturing peach (*Prunus persica* (L.) Batsch) cultivar, grown on GF305 rootstock, was planted in an open vase training system (5 × 4 m). This tree training system had been chosen because it is widely used in the area, and, more globally, in the Mediterranean peach production area (Farina et al. 2006). Approximate dates of flowering, beginning of Stage III (rapid fruit growth) and harvest were 20 March, 20 June and 20 July, respectively. Routine horticultural care for irrigation, fertilisation and soil management was provided. Hand-thinning was carried out in May to leave 10 to 15 cm between fruits along the fruiting shoots in order to ensure suitable fruit size. Crop protection was managed according to the Integrated Pest Management system. However, no plant protection measures were taken against brown rot in order to observe the effect of pruning management on the incidence of this disease.

Experimental set-up

At the end of 2003, the homogeneity of the experimental area (six rows of 25 trees) was checked by measuring tree trunk circumference. The experiments were performed on the four internal tree rows, whereas the two external tree rows were considered as guard rows. The two pruning treatments were randomly applied in three blocks, with six trees in each experimental unit. Two repetitions of each elementary plot were carried out, so that there were 36 ($3 \times 6 \times 2$) trees per treatment. The other trees were considered to be guard trees in order to separate the elementary plots in each experimental row.

Pruning treatments

In peach, ConvP consisted of a dormant (beginning of March) and a summer (around three weeks before fruit maturity) pruning. In this experiment, the ConvP treatment corresponds to the method usually performed by the fruit growers in the area, generally leading to considerable leaf density and shade inside the canopy (Fig. 1A) (Li et al. 1994). CentP in peach, as in the apple training system (Willaume et al. 2004), encourages light penetration within the canopies, especially due to the removal of all young vigorous shoots (potential water sprouts) inserted directly on the scaffold or on the basal part of fruiting branches, which can shade the fruits after they are fully developed (Fig. 1B) (Plenet et al. 2010). This pruning system tends to privilege the shoots located at the end of the one-year-old shoots and to reduce the damage done by pruning shears, which results in vigorous reiterations in some parts of the tree (Lauri et al. 2004). CentP also requires two-fold handling. First, at the same time as for the dormant pruning of the control treatment, shoots that limit light penetration inside the canopy were removed in order to create a "light well" around the scaffold. Second, CentP consisted, in particular, of the removal in spring (April–May) of vigorous shoots of the year (potential water sprouts), mainly located in the centre of the tree. To improve light penetration inside the tree, the leafy shoots on the basal part of the one-year-old shoots and two-year-old woods were also removed. Finally, CentP, which was generally manually performed, can be considered as an early summer pruning.

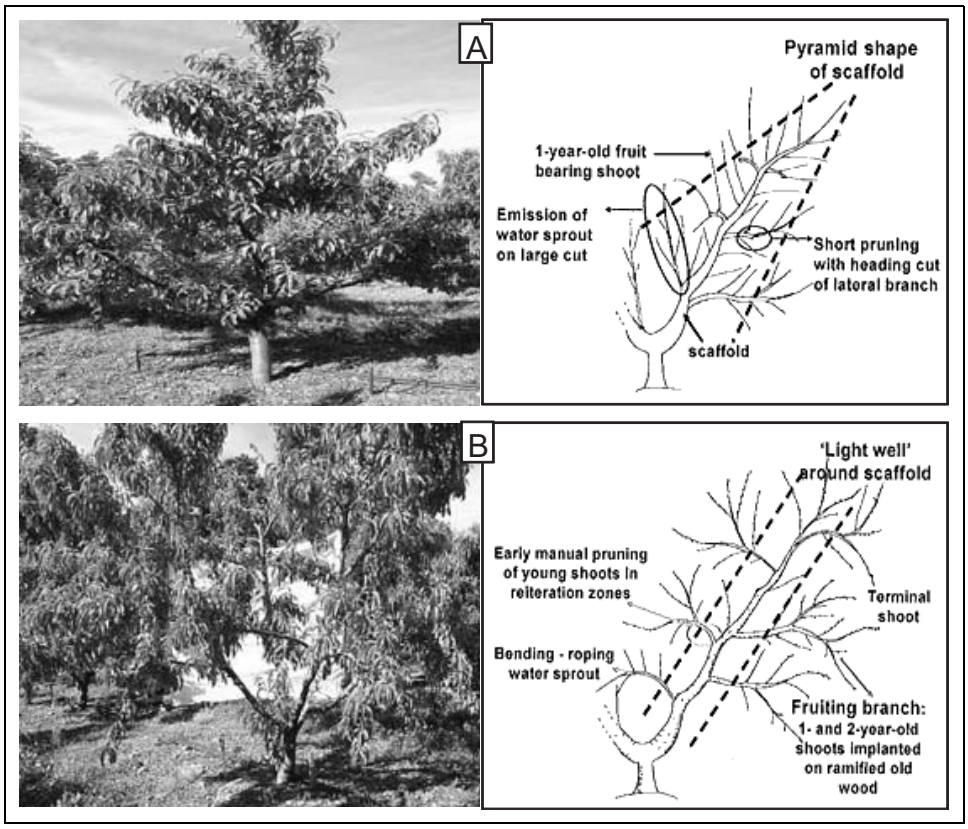


Fig. 1. Conventional (A) and centrifugal (B) pruning systems in peach tree.

Labour demand for training trees was evaluated from 2005 to 2008 in the two repetitions of the first block. The two-fold handling under both training treatments was detailed: dormant (or winter) pruning under the two treatments, manual pruning performed in spring under CentP, and summer pruning under ConvP. Labour demand for thinning was also taken into account under both treatments. Labour demand for harvest was not considered because it was closed to amount of harvested fruits.

Agronomic performance

From 2004 to 2006, the number of flowers per unit FBS (fruit-bearing shoot) length was evaluated from five tagged one-year-old shoots on a sampled tree in each experimental unit. The harvest was completed in three or four pickings. Firmness was evaluated just before harvest using a durometer (Mercier et al. 2008). The purpose was to have fruits picked at the same firmness, i.e. the same firm-ripe stage, over the whole experimental data set. Fruit yield was determined for each experimental unit. Average fruit weights were calculated on a representative sample of fruit production (about 20 % of the total harvest, as defined by Marini and Trout 1984). At harvest, all the fruits of one sampled tree in each experimental unit were graded. Relative returns (euros/ha) were calculated on the basis of tree yield and fruit size distribution in the sampled trees. Fruit sale prices were provided by the Lorifruit Cooperative, where area fruit growers delivered their produce.

Tree growth was partly evaluated every year in winter by measuring the trunk circumference of all the trees at 0.30 m from the ground. Under CentP, water sprout re-growth was evaluated from the early spring pruning until fruit harvest on one scaffold branch per tree for five trees.

Fruit quality

The total soluble solid concentration of each peach was measured for every fruit grade (Bussi et al. 2009). From 2006 to 2008, 30 fruits were randomly sampled at the first picking in each of the six experimental units per treatment in order to evaluate the brown rot incidence per treatment at harvest. In 2008, the post-harvest brown rot incidence was evaluated once again on 30 selected fruits (same diameter, without epidermis defects) sampled at maturity in each experimental unit one day before the first and the second picking date. Fruits were carefully arranged in fruit crates equipped with special packaging material in order to prevent any damage. The fruits were transported from the orchard to a growth chamber and stored under controlled conditions (temperature: 20°C; relative humidity: 75 %) for 10 days. Infected fruits were removed every day to prevent the other fruits from being contaminated.

Statistical analysis

Analyses of variance were performed at each measurement date, at harvest and at post-harvest using the Stat-

graphics Plus v. 5.0 software package. Arcsine square root transformation of the data was included when needed (percentages and brown rot incidence). The comparison of treatments was carried out using Student's T-test, and the significant differences between treatments were identified at the 5 % probability level.

Results

Agronomic performance

Because of early water sprout removal in spring under CentP, significant water sprout re-growth might be expected, but such a trend did not occur (data not shown). Trunk circumferences did not significantly differ under CentP and ConvP, suggesting that tree vigour was not affected by the two pruning treatments (data not shown). On average, from 2004 to 2006, CentP induced +35 % higher flower number per m shoot length with respect to ConvP (Table 1). Each year, trees under CentP had higher tree fruit loads at fruit maturity (+33 % on average, from 2004 to 2008), and higher yields than trees under ConvP (significantly in 2004 and 2007, +29 % on average, from 2004 to 2008) (Table 1). Average fruit weight only slightly differed: −2 % under CentP compared to ConvP on average, from 2004 to 2008 (Table 1). Average fruit weights were significantly higher under ConvP than under CentP only in 2005 (Table 1).

In 2004 and 2008, tree fruit loads tended to be higher under CentP than under ConvP, but not significantly (Table 1). The effect of the two treatments on fruit maturity and grade partitioning was shown for these two years (Table 2 and 3). Percentages of fruits harvested at each

Table 1. Agronomic performances, fruit quality and monetary returns in peach (cv. 'Caprice') subjected to centrifugal (CentP) or conventional (ConvP) pruning. The Probability levels (P) are indicated in each year.

Year	Treatment	Flower number per m shoot length	Number of fruits per tree at harvest	Yield per tree (kg)	Total soluble solids (%)	Average fruit weight (g)	Fruits infected by *Monilia* (%)	Monetary returns (€ tree^{-1})
2004	CentP	35	406	66.4	11.8	164	n.d.	38.7
	ConvP	24	320	51.9	10.5	162	n.d.	30.7
	P value	0.004	0.182	0.028	0.008	0.632		0.031
	LSD (5 %)[a]	5	90	11.2	0.6	9		7.5
2005	CentP	44	570	85.5	10.7	150	n.d.	43.3
	ConvP	35	466	77.1	10.6	166	n.d.	41.5
	P value	0.051	0.035	0.292	0.320	0.025		0.510
	LSD (5 %)	9	98	16.4	0.7	12		14
2006	CentP	60	758	112.2	9.9	148	2.5	62.5
	ConvP	45	626	95.4	9.6	153	3.3	58.2
	P value	0.020	0.119	0.132	0.155	0.450	0.310	0.410
	LSD (5 %)	11	139	21.6	0.5	16	2.0	20.0
2007	CentP	n.d.	627	106	11.4	171	2.5	45.8
	ConvP	n.d.	331	58.1	11.8	177	5.5	25.8
	P value		0.004	0.006	0.450	0.333	0.04	0.008
	LSD (5 %)		150	32.0	0.6	15	2.4	15.0
2008	CentP	n.d.	263	46.3	10.3	177	1	26.4
	ConvP	n.d.	226	39.3	9.6	174	0.8	22.3
	P value		0.320	0.554	0.025	0.225	0.740	0.252
	LSD (5 %)		65	11.7	0.4	14	0.6	9.0
Mean 2004–2008	CentP	46	525	83.3	10.8	162	2.0	43.3
	ConvP	35	394	64.4	10.4	166	3.2	35.7
	P value	0.022	0.040	0.035	0.102	0.225	0.150	0.029
	LSD (5 %)	7	100	15.7	0.6	10	1.5	6.0

[a] Least-square difference at $P < 0.05$; n.d. = not determined.

Table 2. Weight (% of total) of harvested peach (cv.Caprice) in terms of centrifugal (CentP) or conventional (ConvP) pruning at each picking date in 2004 and 2008. The Probability levels (P) are indicated in each year.

Year	Treatment	Picking date				Total picking
		1st	2nd	3rd	4th	
2004	CentP	17.1	26.2	33.0	23.7	100
	ConvP	14.6	25.5	30.4	29.4	100
	P value	0.120	0.450	0.580	0.155	
	LSD (5 %)[a]	5.1	10.4	8.4	10.1	
2008	CentP	23.4	43.2	19.5	13.9	100
	ConvP	9.4	43.5	26.0	21.2	100
	P value	0.002	0.350	0.085	0.032	
	LSD (5 %)	6.3	10.2	9.0	6.2	

[a] Least-square difference at P < 0.05.

Table 3. Fruit weight (% of total harvest) and total soluble solids (TSS) in terms of centrifugal (CentP) or conventional (ConvP) pruning according to peach (cv. 'Caprice') grade in 2004 and 2008. Grade AAA corresponds to a diameter of 80–90 mm, AA to 73–80, A to 67–73, B to 61–67. For each treatment, TSS were evaluated in fruits of grade AAA (TSS AAA), grade AA (TSS AA), grade A (TSS A) and grade B (TSS B). The Probability levels (P) are indicated in each year.

Year	Treatment	Grade AAA		Grade AA		Grade A		Grade B	
		%	TSS	%	TSS	%	TSS	%	TSS
2004	CentP	0.6	13.8	20.2	11.3	79.2	11.3	0.0	
	ConvP	0.3	12.5	13.3	9.4	86.4	11.0	0.0	
	P value	0.045	0.002	0.025	0.001	0.420	0.350		
	LSD (5 %)[a]	0.3	0.8	5.4	0.7	18.4	0.9		
2008	CentP	14.6	11.1	48.8	10.5	35.0	9.7	1.7	9.2
	ConvP	14.2	10.3	45.4	10.0	37.3	9.0	3.1	8.5
	P value	0.450	0.006	0.420	0.045	0.550	0.020	0.120	0.102
	LSD (5 %)	4.2	0.5	15.2	0.4	12.0	0.5	1.5	1.0

[a] Least-square difference at P < 0.05.

picking date significantly differed in 2008: more than two times as many fruits were picked at the first harvest under CentP than under ConvP (Table 2). In 2004, high grades (AAA and AA) were significantly more common under CentP than under ConvP; in 2008, no difference occurred (Table 3).

With respect to those under ConvP, relative monetary returns tended to be higher under CentP (significantly in 2004 and 2007, +21 % on average, from 2004 to 2008) (Table 1).

Labour demand for pruning and thinning

Labour demand for pruning and thinning under CentP was between 14 and 24 % higher than that under ConvP from 2005 to 2008 (+18 % on average) (Fig. 2A). When expressed as a percentage of the total labour demand, tree training under CentP was almost equally divided into dormant pruning, spring pruning and thinning, without any labour demand spent in summer. However, under ConvP, summer pruning represented 16 % of the total labour demand (Fig. 2B). The labour demand devoted to dormant pruning and to thinning under CentP tended to be less (−25 %) than that under ConvP (Fig. 2B).

Fruit quality

Despite the discrepancy in yield between the two treatments, fruit total soluble solids (TSS) tended to be higher under CentP compared to ConvP (significantly in 2004 and

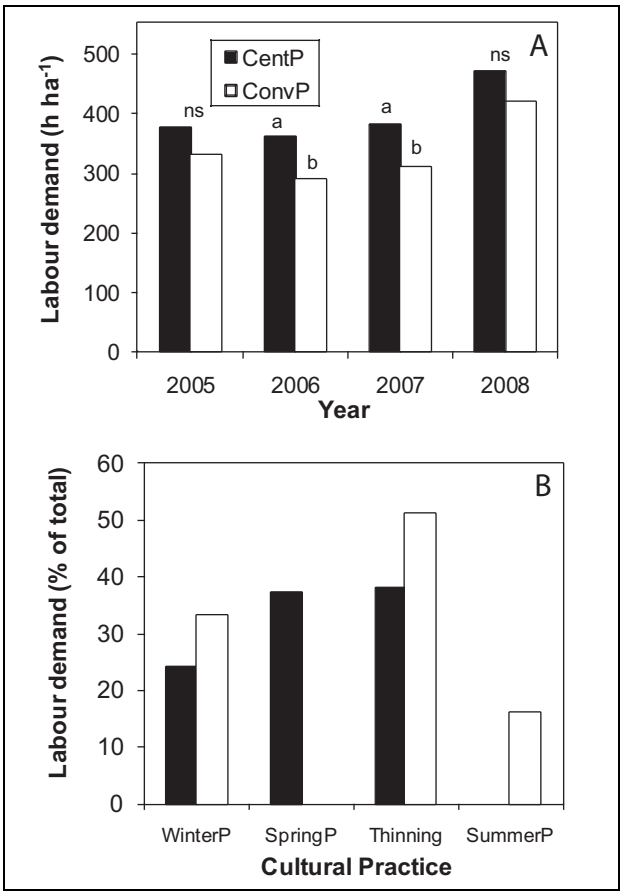


Fig. 2. Labour demand, h per ha (A) and % of total (B), in peach orchard in relation to centrifugal (CentP) or conventional (ConvP) pruning from 2005 to 2008. WinterP = Winter Pruning, SpringP = Spring Pruning, SummerP = Summer Pruning. Data followed by different letters were significantly different at $P < 0.05$; ns: not significant.

2008, +4 % on average, from 2004 to 2008) (Table 1). Except for the lowest one, the different peach grade effectively exhibited more TSS under CentP than under ConvP in 2004 and 2008 (Table 2).

In 2006 and 2007, the brown rot incidence close to fruit maturity was lower under CentP than under Conv P (significantly in 2007) (Table 1). In 2008, the brown rot incidence was very low (around 1 %) at fruit maturity (Table 1). Under 2008 post-harvest storage conditions, brown rot incidence tended to be lower under CentP than under ConvP between six and nine days after the first picking (Fig. 3A). This trend became significant for the fourth and fifth day after the second picking (−44 % lower under CentP than under ConvP on average) (Fig. 3B).

Discussion

Peach productivity was enhanced under CentP compared to ConvP. The higher flowering rate induced under CentP contributes to this higher fruit production (Plenet et al. 2010). Besides, removing water sprouts early in spring, as was done under CentP, probably contributes to enhancing light penetration within the tree canopy compared to ConvP, as shown in apple (Willaume et al. 2004). Moreover, it was reported that the proximity between fruit and assimilate source on peach shoots enhanced carbohydrate supply to the fruit (Corelli-Grappadelli and Coston 1991), suggesting that fruit and young shoot proximity in the peripheral part of the tree under CentP was likely to improve fruit productivity compared to ConvP. The improvement of light penetration and of fruit and young shoot proximity could also explain the hastened fruit maturity and the higher peach sugar content under CentP compared to ConvP, since the result of increasing fruit productivity usually led to a decrease in peach quality (Volz et al. 1993).

The trend towards higher total soluble solids under CentP with respect to ConvP showed that this innovative method was likely to improve peach quality for a medium-maturing cultivar. Greater sugar content in peach can be identified as a quality improvement because the taste of these peaches was usually preferred by the consumer (Gelly et al. 2004). This peach taste improvement, concomitant to the higher peach productivity under CentP compared to ConvP, suggested that fruit production was qualitatively and quantitatively improved under CentP as shown in apple (Lauri et al. 2004). The simultaneous reduction in fruit diameter generally detected under CentP with respect to ConvP (Plenet et al. 2010) was shown to be limited at peach maturity. As a result, because harvested peach grade partitioning was only slightly affected and yield largely enhanced, monetary returns tended to be higher under CentP than under ConvP for each of the five years of the experiment.

Labour demand increased under CentP compared to ConvP, in the same proportion as monetary returns, so that the supplemental costs due to this innovative pruning method tended to be economically compensated for by higher fruit production. Under CentP, in contrast with ConvP, no labour demand was devoted to pruning in summer, which is considered to be the busiest time of the year for fruit producers, whereas less labour in the orchard is generally required in early spring (Plenet et al. 2009). Water sprouts were removed in spring under CentP and in summer under ConvP, implying that the innovative method is more advantageous in terms of labour management for the producer. CentP therefore appeared likely to improve the labour organisation of peach growers compared to ConvP.

The trend towards a lower incidence of brown rot at fruit maturity and until fruit storage in the peach orchard under CentP compared to ConvP suggested that CentP contributes to decreasing medium-maturing peach sensitivity to brown rot. This observation was in accordance with results already obtained under manual pruning with a late-maturing nectarine cultivar (Mercier et al. 2008). English et al. (1989) and Houma et al. (1998) demon-

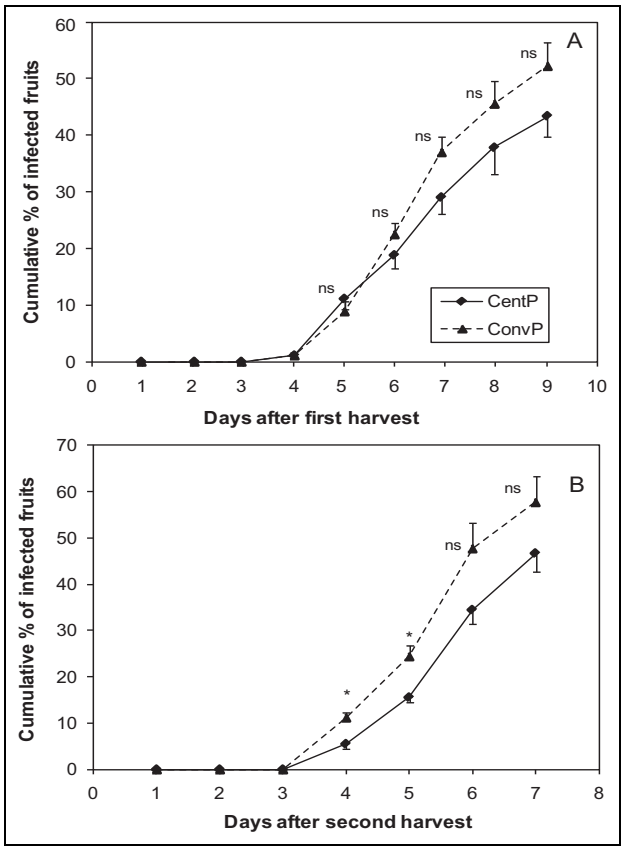


Fig. 3. Time-course of brown rot incidence on peach under post-harvest storage conditions at the first (A) and at the second (B) picking in 2008 in relation to centrifugal (CentP) or conventional (ConvP) pruning. Vertical bars denote standard error. * indicates significant differences at $P < 0.05$; ns: not significant.

strated that Botrytis bunch rot of grape could be suppressed by removing leaves from around flower clusters. Holb (2005) showed that scab was limited in apple trees under severe pruning compared to unpruned trees. These disease limitations were mostly caused by the difference in the moisture content of air in the plant canopy. Under our conditions, a similar hypothesis can be proposed to explain limited brown rot incidence under CentP. According to this hypothesis, this pruning method would adversely affect the germination and sporulation of the fungus by inducing more aeration and lower humidity around the peach. The limited incidence of brown rot under CentP could possibly contribute to the important challenge for fruit growers concerning the reduction of the use of fungicides in peach orchards.

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Addresses of authors: Claude Bussi (corresponding author), INRA, UE 695 Unité Expérimentale Recherches Intégrées, F-26320 St. Marcel-les-Valence, France, and D. Plenet, INRA, UR 1115 Plantes et Systèmes de Culture Horticoles, Site Agroparc, F-84914, Avignon Cedex 9, France, e-mail (corresponding author): Claude.Bussi@avignon. inra.fr.