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Effect of centrifugal tree training on pests and pathogens in apple orchards

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Abstract: The effect of tree architecture on the development of the main apple pests and pathogens was investigated from 2002 to 2005 at the INRA Gotheron experimental station. The original Solaxe (OS) was compared to the centrifugal training (CT) system, in which the thinning out of fruiting spurs along the trunk and on the proximal and underside parts of branches modifies within-tree environment conditions. Infestation levels of the rosy apple aphid *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae) and of the European red mite *Panonychus ulmi* (Koch) (Acari: Tetranychidae) were significantly lower in the CT than in the OS system, in 2002 and 2004 for *D. plantaginea*, and in 2003 for *P. ulmi*. For the green apple aphid *Aphis pomi* De Geer (Hemiptera: Aphididae), differences between systems varied with years. Fruit damage by the codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) tended to be higher in the CT than in the OS system. The incidence of apple scab *Venturia inaequalis* (Cooke) G. Wint. was lower in Spring (2002, 2004) in the CT than in the OS system, but increased faster in CT than in OS in Summer, with no difference in fruit damage at harvest. Due to several factors, including pest or inoculum removal when thinning out spurs, within-tree microclimate, shoot density and/or growth dynamics, tree architecture influences the development of pests and pathogens. These results open a wide field of research on the use of tree architecture as a means to modulate pest and disease development.

Key words: apple, tree architecture, centrifugal training, pest, disease, pest control

Introduction

Relationships between tree structure and pest infestations or pathogen infections have long been recognised (Wildbolz, 1982; Brown and Walker, 1992), but seldom investigated. In apple orchards, centrifugal training (CT), based on the extinction procedure (Lauri *et al.*, 2000; Lauri *et al.*, 2004), has been used for some years by French growers of the apple MAFCOT network (MAFCOT, 1999). This procedure (i.e., thinning out of fruiting spurs) modifies durably branch and leaf density and distribution within the tree, optimising light distribution, fruit colour and return-bloom (Lauri, 2002; Willaume *et al.*, 2004). Artificial extinction also changes shoot demography by increasing the proportion of long shoots (Lauri *et al.*, 2004). CT is therefore likely to: (i) modify canopy aeration, and (ii) alter vegetative growth dynamics and rhythmicity, potentially affecting the development of some foliar pests or pathogens.

The aim of this study was to assess the impact of CT on pest and pathogen development, and to compare this to a more common type of apple tree training (Original Solaxe; Lauri and Lespinasse, 2000).

Material and methods

Experimental orchards

The study orchards (Table 1) were located in the Middle Rhone Valley, at Saint-Marcel-lès-Valence (France), in a continental area with Mediterranean influences. Rows were North-South oriented. The alleys between rows were sown with grass, which was mowed regularly. As weed control, tillage was performed within the rows. The orchards were surrounded with hedgerows (North and South sides), fallow fields or apple orchards (East and West sides).

Table 1. Experimental orchards.

	Orchard I	Orchard II
Soil	shallow stone soil of old washed-out Rhone River sediments	
Cultivar / rootstock	Smoothee 2832T®/ M9	Pitchounette & Ariane / M9
Planting date	1994	2001
Tree spacing	4 m x 2 m	4.5 m x 2 m
Orchard management	Organic farming (hand-thinning only)	Integrated Pest Management
CT trees: first year for artificial extinction	2002	2004: Ariane 2005: Pitchounette
Pest disease assessment	aphids, mites, scab: 2002-2005	codling moth: 2005

In both orchards, one spray with mineral oils was applied each year in the dormant season against overwintering forms. According to the infestation level, pre-bloom sprays (Orchard I) or pre- and post-bloom (Orchard II) sprays were applied against *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae). Granulosis virus alone (Orchard I), and granulosis virus then phosalone (Orchard II) were sprayed against codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). For any risk of infection, Orchard I was sprayed preventively against scab *Venturia inaequalis* (Cooke) G. Wint. with copper or sulphur. No fungicide was sprayed against scab in Orchard II (scab resistant cultivars).

Table 2. Training procedures: Original Solaxe (OS) and Centrifugal Training (CT) systems.

Procedure (time of application)	OS	CT
- Renewal of vigorous branches on the upper side of the already established fruiting branch (Winter)	YES	YES
- Heading cut[1] / shortening cut[1] of the leader branch (Winter)	NO	NO
- Thinning cut[1] of fruiting spurs, i.e. artificial extinction, along the trunk and on the proximal and underside of branches (bloom)	NO	YES
- Chemical thinning and/or hand-thinning (end of physiological drop)	YES	YES
- Branch bending (growing season)	YES	YES

[1]Terminology according to Barritt (1992).

Tree training systems and experimental design

Trees were initially trained according to the Original Solaxe training system (OS) (Lauri and Lespinasse, 2000; Table 2). At bloom in April, the two experimental orchards were split into the following two treatments: (i) OS trees with the same training as in previous years, thereafter considered control trees; and (ii) CT trees (Table 2; Figure 1).

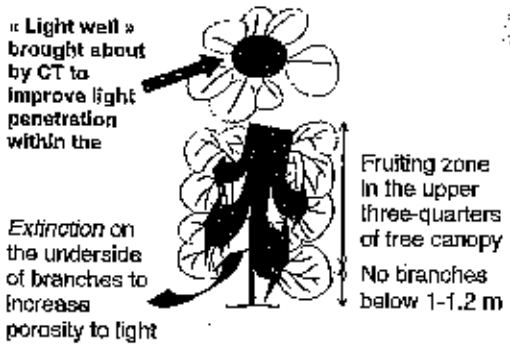


Figure 1. Centrifugal training (CT)

On these CT trees, no or only complementary artificial extinction was then required on the newly grown branches. In both treatments, the target fruit-load was similar, with one fruit left per flower cluster.

Treatments were replicated four times with a block design. Each block consisted of two plots, one CT, and the other managed according to the OS training system. The orchards' border rows were not included in the study.

Pest and disease assessment

In orchard I, on 13 trees randomly selected within each plot, aphids (*D. plantaginea*, *Aphis pomi* De Geer (Hemiptera: Aphididae)), European red mites *Panonychus ulmi* (Acari: Tetranychidae) and apple scab were visually assessed (ACTA, 1974) during the growing season from 2002 to 2005. In orchard II, 20 trees randomly selected within each Ariane and Pitchounette plot were visually assessed for codling moth fruit damages during 2005 growing season. The position within the canopy (outer, middle, and inner) of the infested fruits was also recorded.

Results and discussion

Differences observed between training systems are summarised (Table 3) and detailed below.

Aphid infestation

In 2002, after pre-bloom treatments against *D. plantaginea*, the orchard infestation (Figure 2) decreased initially in March, then increased considerably in May, with a peak at 83.5% infested shoots. From mid-June onwards, migration of *D. plantaginea* to its secondary host, *Plantago* sp., explained the decrease in infestation. Before starting the experiment, prior to

artificial extinction carried out at bloom in CT trees, a similar infestation was observed among blocks (4% infested shoots on 26 March 2002). Later in 2002, CT trees tended to be less infested than OS trees and treatments were significantly different on 15 May (Figure 2). At harvest, CT trees had less fruit damage compared to OS ones (Figure 2).

In 2004, the infestation level was low and similar in both training systems (3% infested shoots on 10 May). A large increase in infestation occurred in mid-May, and treatments displayed then a significant difference (24.0% and 46.2% infestation on 24 May, respectively; P=0.0438).

Table 3: Effect of Centrifugal Training (CT) on pest and disease development in both experimental orchards, compared to Original Solaxe (OS).

Years with:	infestation or infection	less infestation or infection in CT compared to OS[1]	less infestation or infection in OS compared to CT[1]
Orchard I (2002-2005)			
- *D. plantaginea*:			
. shoot infestation	2002, 2003, 2004, 2005	2002, 2004	-
. fruit damage at harvest	2002, 2003, 2004, 2005	2002	-
- *A. pomi* shoot infestation	2002, 2003, 2004	2003	2002, 2004
- *P. ulmi* leaf infestation	2002, 2003	2003	-
- *V. inaequalis*:			
. spring infection	2002, 2004, 2005	2002, 2004	2005
. fruit damage at harvest	2002, 2005	-	-
Orchard II (2005)			
- *C. pomonella* fruit damage:			
. end of first generation	2005	-	Ariane: 2005
. harvest	2005	-	Ariane: 2005

[1] Years with at least one assessment date showing statistical significance between systems.

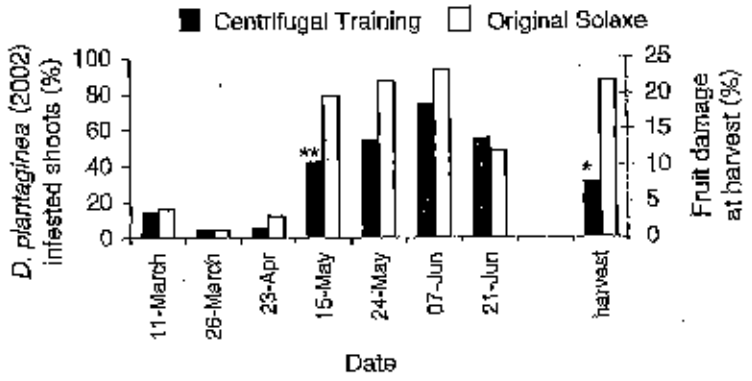


Figure 2. Infestation by the rosy apple aphid *D. plantaginea* in the Centrifugal Training (CT) and the Original Solaxe (OS) systems in 2002.
Statistical significance at P<0.05 and P<0.01 is indicated by * and **, respectively.

A. pomi colonies that developed within the orchard in May were due mainly to immigrating winged aphids. During Spring 2002 and 2004, infestation tended to be higher in CT than in OS trees, and the difference between training systems was significant on late June (70.3% and 56.2% infested shoots in CT and OS trees on 21 June 2002, respectively; P=0.0414; 44.2% and 33.7% on 22 June 2004; P=0.0463). In June 2003, infestation in OS increased much more than in CT, and the difference was significant on 5 June (53.8% and 74.0% infestation in CT and OS trees, respectively; P=0.0281).

European red mite infestation

In 2002, leaf infestation peaked at means of 34.6% and 60.6% in the CT and OS treatments, respectively (19 August; P=0.1588). In June 2003, infestation was significantly lower in CT than in OS trees (35.6% and 43.3% infested leaves on 11 June in CT and OS trees, respectively; P=0.0319).

Codling moth infestation

By mid-July, infestation levels in Ariane trees due to codling moth 1st generation reached its maximum. At that moment, a significantly higher infestation was observed in CT trees (P=0.026) (Figure 3). These differences increased for 2nd generation damages, and total damage recorded at harvest was 4.1% for CT, whereas OS had a significantly lower amount of fruit damaged (2.5 %, P=0.004). In Pitchounette, the infestation level was low and similar for 1st generation larvae (0.54% and 0.33% for CT and OS, respectively; P=0.244). Though infestation levels due to 2nd generation for CT were significantly higher and nearly doubled the observed in OS (P=0.046, not shown), overall account for infested fruits at harvest (1st + 2nd generation) was not significantly different (Figure 3).

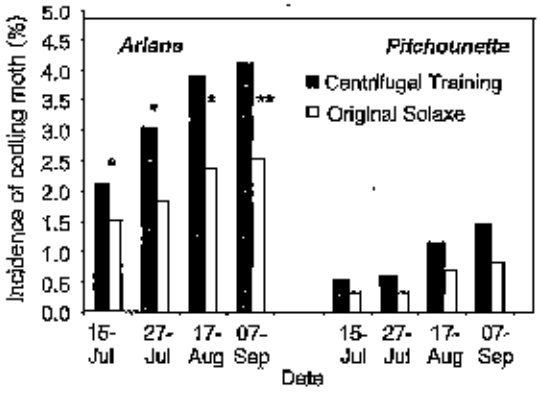


Figure 3. Infestation by codling moth (*Cydia pomonella* (L.)) in Centrifugal Trained and Original Solaxe trees in 2005.
Statistical significance at P<0.05 and P<0.01 level is indicated by * and **, respectively.

The influence of the treatment in the distribution of the infested fruit within the canopy was very similar for both cultivars (Table 4): in OS more than two thirds of the infested fruits were placed in the outer third of the tree, and the rest were more or less evenly distributed in the middle and inner parts. The distribution pattern was significantly different (P=0.0001 and

P=0.003, respectively) in CT trees, as only half of the fruit were placed in the outer third of the canopy. In the less ramified cultivar Ariane, 25% of damaged fruit were placed in the inner third.

Table 4. Situation (%) of the codling moth infested fruit within the canopy in the Centrifugal Training (CT) and Original Solaxe (OS) systems.

Position within the canopy	Ariane		Pitchoumette	
	CT	OS	CT	OS
Outer	53.1	68.8	50.9	67.7
Medium	22.4	17.2	43.4	19.4
Inner	24.5	14.1	5.7	12.9
Significance	*		**	

Statistical significance at P<0.05 and P<0.01 is indicated by * and **, respectively.

Apple scab infection

Spring and summer 2002 were exceptionally damp and therefore highly favourable to scab. Scab infection increased considerably during May and June, despite sulphur spraying. During May, treatments did not significantly differ but late June CT trees were less scabbed than OS ones (leaf scab incidence: CT mean = 0.717, OS mean = 0.783 on 20 June; P=0.0128). Significant differences in fruit infection were observed in June and July, when approx. 30% less fruit damage was observed in CT trees compared to OS trees. During August, the percentage of scabbed fruit increased faster in CT than in OS trees, resulting in no difference between treatments at harvest (69.4% scabbed fruit on 6 September).

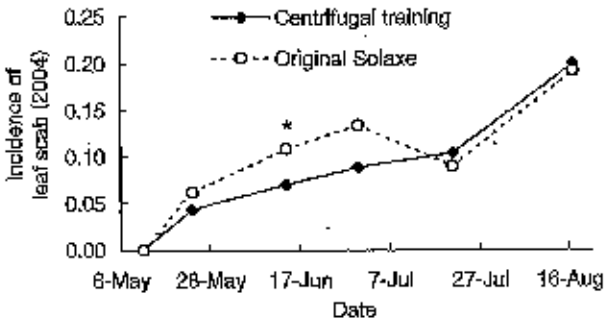


Figure 4. Incidence (ratio of the number of scabbed leaves to the total number of leaves) of scab on leaves in centrifugal trained (CT) and original Solaxe (OS) trees in 2004. Statistical significance at P<0.05 is indicated by *.

In 2004, scab lesions were recorded from 24 May onwards (Figure 4). The incidence of leaf scab then increased until late August, while the percentage of scabbed fruit remained very low until fruit harvest. On 14 June, the incidence of leaf scab was lower in CT trees than in OS trees (Figure 4). No further difference in scab incidence was observed between treatments

in July and August. In 2005, leaf scab incidence was similar in CT and OS systems, but the number of scab lesions per leaf was higher in CT trees than in OS trees in June. Fruit damage at harvest was not different between systems (45.6% scabbed fruit on 13 September).

Hypotheses on pest and pathogen development as affected by canopy structure

Significant differences in pest infestation and pathogen infection were observed between the two training systems. An effect of the apple tree structure and growth on the pest and disease status of the orchard was thus demonstrated. Interacting hypotheses related to canopy structure were proposed (Simon *et al.*, 2006) and main factors involved were likely to be: (i) pest or inoculum removal, at the thinning cut of fruiting spurs; (ii) decrease of leaf wetness periods, due to the increase in light penetration within the canopy (Willaume *et al.*, 2004); (iii) decrease in connectivity between shoots, associated with the CT canopy structure, with an effect on the rate at which pests could spread; (iv) resource availability in attractive foliage or susceptible leaves at a given time.

D. plantaginea aphids observed on shoots in early Spring had issued from overwintering eggs whereas *A. pomi* immigrated in May from the surroundings of the orchard. As a similar infestation was recorded in both training systems before artificial extinction in 2002 and in 2004, differences in *D. plantaginea* infestation levels could not be related to differences in overwintering egg numbers, or winter survival rates. Pest removal is likely to explain why significant differences in *D. plantaginea* infestation were observed between training systems just after artificial extinction in 2002. The effect of canopy structure *via* among-shoot connectivity could be hypothesised from the 2004 results, showing a far higher *D. plantaginea* infestation rate in OS trees than in CT trees between 10-24 May, whereas the two training systems exhibited similar infestations on 10 May. Late June infestations of *A. pomi* were most probably related to a longer growth period in CT trees (Lauri *et al.*, 2004), to the benefit of newly-arriving aphids. Besides, we cannot exclude the co-existence of two interconnected levels: (i) the level discussed above between plant and hosts, and (ii) the between-hosts level, with competition for resources between the two recorded aphids.

In August 2002, the level of infestation of *P. ulmi* was unusual in this organic orchard, and could be related to scab management with sulphur (Kreiter *et al.*, 1998), that was used throughout the entire season. The significant difference observed in 2003 was most probably related to late Summer 2002 populations, which tended to be lower in CT trees compared to OS trees. A slower infestation rate (more time to spread) related to a lower branching density in CT trees compared to OS trees, or differences in the availability in attractive foliage between treatments, are likely to explain this trend. However, the long-term effects of CT on mites cannot be assessed because of the natural control of this pest provided within the orchard by the *Orius* sp. predatory bug (Hemiptera: Anthocoridae).

The higher infestation levels observed for *C. pomonella* in CT trees may be attributed to the lower shoot density of those trees, increasing fruit accessibility for adults of codling moth. So, egg-laying in the inner part of the tree is favoured, as assessed by the higher number of inner-canopy infested fruit. This hypothesis is supported by the branching habits of the cultivars used in this study: in the densely ramified Pitchounette, CT allowed codling moth spreading mainly over the two outer thirds of the canopy, whereas in Ariane, scarcely ramified and so more accessible, fruit placed in inner canopy were more attacked.

During spring, the increase in fruit and leaf scab was slower in the 2002 and the 2004 CT treatments. This could be explained by: (i) the removal of inoculum during the thinning cut of spurs; and/or (ii) the canopy microclimate. The reduction in leaf density induced by CT (Willaume *et al.*, 2004) probably led to shorter periods of wetness and less scab infection. During Summer, scab increased faster in CT trees than in OS trees. As in 2004 shoot growth (data not shown) was greater from 24 May to 30 June in CT trees (3.9 newly grown leaves)

than in OS trees (3.0 newly grown leaves), the availability in young apple leaves more susceptible to scab than old ones (Schwabe, 1979) is likely to explain the higher degree of scab development observed in CT trees than in OS ones.

Conclusions

These experiments provide the opportunity to investigate the relationships between manipulation of tree-architecture and pest and pathogen development. Information has been provided on pest and pathogen susceptibility in CT compared to OS systems. The effects observed were beneficial for the control of some pest and disease: less damage of *D. plantaginea*, lower mite infestation, less spring scab infection. Some of these effects were not substantial or stable: null benefit at harvest for scab, unsteady results for *A. pomi*. Last, depending on the cultivar, the effect for codling moth control could be detrimental, with higher infestation in the inner part of CT trees. The innovative CT concept, which proved to be beneficial in terms of the balance between fruiting and vegetative growth (Lauri *et al.*, 2004), had thus a partial effect on the pest and disease status of the orchard.

Several hypotheses are now to be tested, in order to provide basic knowledge for the manipulation of tree architecture, an effective and sustainable cropping practice for partially regulating pest infestation in orchards.

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