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Scab control in organic apple production: conclusions of an eight year study in temperate weather conditions

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Abstract: The objective of this study, conducted over eight growing seasons (2002–2009), is to identify an innovative way for reducing the use of fungicides and in particular, copper fungicides, for the control of apple scab (*V. inaequalis*) in organic apple production. Special emphasis is put on cultivar traits, sanitation practices and primary scab infection control during spring season. An original approach is proposed for defining a specific spray timing involving spraying during the infection processes, especially before fungal penetration, determined by the RIMpro software warning system. This 'during-infection' spray strategy allows reducing from 30 to 50% the amount of fungicide usually used for effective apple scab control, on high scab-susceptible cultivars. Potassium bicarbonate, lime sulphur, and three plant extracts such as peel orange extract, among 60 alternative products tested, have the potential to reduce copper use. However, copper use, even with low doses, seems to be still necessary in presence of scab-susceptible cultivars. The results obtained in these experiments could not be attributed to the specific technical performances of the tunnel sprayer used, which however, offer valuable environmental benefits. This work shows that (i) planting cultivars with polygenic scab-resistance traits, (ii) increasing accent on sanitation practices aimed at reducing initial inoculum in autumn, and (iii) applying an accurate "during-infection" spray strategy in spring, are the three most promising approaches for substantial further reductions in protection products fully compliant with international organic crop production standards.

Key words: Apple, disease control, friendly environmental management, natural plant extract, orchard, spay drift

Introduction

Under Belgian weather conditions, apple scab caused by *Venturia inaequalis* [Cooke] Winter is a major disease in apple production. Most of the commercial apple cultivars are very susceptible to scab. In commercial apple orchards very frequent fungicide applications (15-22 annually) are needed to control apple scab, depending on weather conditions, disease pressure and cultivar susceptibility (Sauphanor *et al*., 2009). Environmental considerations are becoming increasingly important and interest has therefore turned from conventional or integrated production to organic apple production. In addition, consumers increasingly demand apples free of any synthetic chemical residues.

There are only a few approved chemical compounds available for disease control following organic guidelines (EC, 2008). They are based mainly on sulphur and copper. A new EU Council Regulation (EC, 2009) allows only a reduced input of copper fungicides. In some European countries, the use of copper fungicides is not allowed. Sulphur compounds are often less effective than copper-based compounds, especially in cold weather (Holb *et al*., 2003). Most sulphur compounds have poor curative properties, the exception being lime sulphur, which might have curative properties against apple scab (Holb *et al*., 2003). Lime sulphur, is currently not allowed to be used in several European countries, although its use is permitted under EU regulations for organic production (EC, 2008). The repeated application of large amounts of sulphur compounds might have phytotoxic side-effects (Holb *et al.*, 2003).

Organic growers often adopt a preventive control strategy that requires more treatments and non-useful treatments. Early warning systems based on disease forecasting models that give timely information about apple scab infection periods have the potential to limit the use of fungicides (Trapman and Polfliet, 1997; MacHardy *et al.*, 2001; Jamar *et al.*, 2008).

An after-infection programme can significantly reduce fungicide applications for scab control (Olivier, 1986; Funt *et al.*, 1990; Holb *et al.*, 2003; Brun *et al.*, 2010). However, this technology, including the after-infection spray approach, has not been widely adopted by organic growers, probably because of the lack of (i) compounds with curative properties and (ii) an accurate local warning system, including weather forecast management.

The aims of this 8-year study is to contribute to the reduction of copper for primay scab control in organic apple production by evaluating the relative effectiveness of four inorganic fungicides (wettable sulphur, lime sulphur, potassium bicarbonate and copper) and several natural plant extracts (e.g.: orange peel, soapbark, tea and quinoa seed), used alone or in combination, following the 'during-infection' spray strategy. The during-infection spray strategy is used as an alternative to the preventive and curative approaches. The effects on scab, yield and fruit quality were studied for high, medium and low scab-susceptible cultivars in a current apple orchard system.

Material and methods

The study was conducted over a period of 8 years, from 2002 to 2009, in two experimental apple orchards planted in 2002 at Gembloux, Belgium. The first orchard was composed of one high scab-susceptible cultivar (cv. 'Pinova'), one medium scab-susceptible cultivar (cvs. 'Pirouette'), one low scab-susceptible cultivar ('Reinette Hernaut') and one very low scab-susceptible cultivar ('Reinette Capucins') (Jamar *et al.*, 2008). The second orchard was composed of four *Vf* scab-resistant cultivars (cvs. 'Initial', 'Topaz', 'Zvatava' and 'JN 20/33/58'). The trees were grafted on dwarfing rootstocks (interstem of cv. 'Golden Delicious') and planted in a single row system (3.5 x 1.5m). A split-plot design based on six randomized blocks with six replicates was used in each orchard. Each block comprised six rows (plots) of 24 dwarf trees. The plots consisted of 24 trees of four cultivars. The cultivars were randomized to subplots within the plots in 4 mono-cultivar groups of 6 trees. Tree density was 1900 trees ha^{-1} in blocks, however, taking into account the presence of 20% of ecological zones situated between blocks, the tree density in the whole experimental orchard correspond with 1500 trees ha^{-1}. The trees were grown according to the organic production standards (EC, 2008). It received each year about 50 units of nitrogen from organic fertilizers.

Potentiel infection periods, based on the Mills criteria, were recorded in the field using a METY computer-based weather recorder connected to the RIMpro scab warning system (Trapman and Polfliet, 1997). Each year, the experiment was conducted on 1440 trees and involved 10 experimental spray treatments. The treatments were randomized in plots within each of the 12 blocks. To prevent spray-drift and to reduce pesticide dispersal, the treatments were applied using a tunnel sprayer (Munckhof). All treatments were applied at a low spray rate of 300l ha^{-1}.

In each year, the treatments were applied during the potential primary infection period identified by the RIMpro scab warning system. The treatments were applied during the infection process, after ascospore inoculation and before hypha penetration (Figure 1). In practice, the treatment timings, defined as the number of hours multiplied by the mean temperature in degrees Celsius (degree-hours, DH) between the onset of rain (associated with infection) and the time of application, were always between 50 and 320 DH. To anticipate infection periods, the extrapolation system of RIMpro, using the short-term weather forecasts, was used. A delayed spray treatment, consisting of spraying 12-24 h after the 'during-infection' spraying, was also implemented in 2006 with lime sulphur.

In the first orchard, the six spray treatments were: (1) untreated control (UC1); (2) potassium bicarbonate-based compounds (AR1); (3) depending on the year, wettable sulphur, delayed lime sulphur, soapbark, tea seed or quinoa seed (SF1); (4) depending on the year, wettable sulphur, copper combined with orange peel (RE1); (5) lime sulphur (LS1) and (6) wettable sulphur combined with copper from the hydroxide form (CS1). In the second orchard, there were four spray treatments: (1) untreated control (UC2); (2) wettable sulphur, (SF2); (3) combinations of copper and wettable sulphur (RE2); and (4) other combinations of copper and wettable sulphur (CS2) (Jamar, 2011).

Regarding the replacement of copper for scab control, the selection of alternative products used in this study was based on preliminary experiments achieved on apple seedlings under controlled environment. A total of 60 alternative products were tested (Jamar, 2011).

Sanitation practices that reduce the population of *V. inaequalis* were partially achieved during this study by shredding and ploughing the leaf litter into the soil.

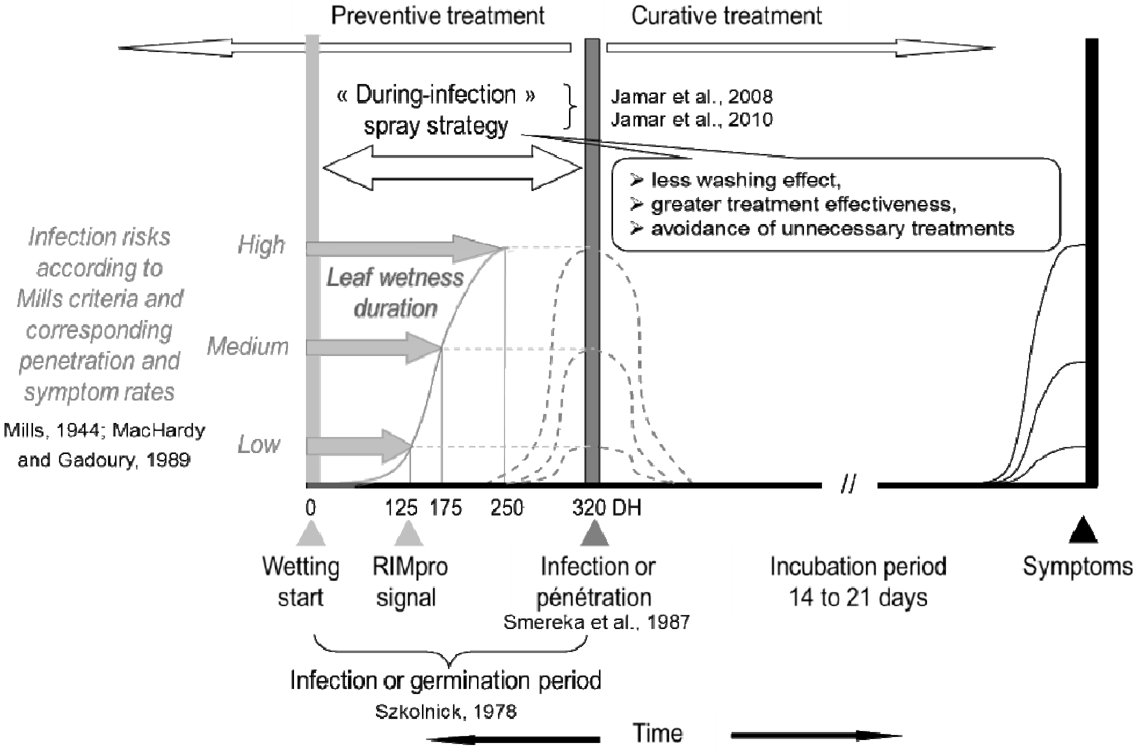

Figure 1: Schematic illustration of the 'during-infection' spray timing (treatment applied 0-320 degree-hours [DH] after the wetting start) in relation to minimum leaf wetness duration, infection risks according to revised Mills criteria, fungus (*V. inaequalis*) activity and the approximate RIMpro infection starting point.

Results and discussion

A new model for optimal spray timing

Eight to ten treatments were applied during the primary infection periods, from March to mid-June, in each year. An average of two additional treatments was applied during the summer. The results presented in this study show that the 'during-infection' spray strategy offers valuable advantages for effective apple scab control with a reduced amount of fungicide use, such as sulphur and copper, on high scab-susceptible cultivars and under conditions conducive to scab infections (Figure 2). The most efficient spray treatments used for apple scab control in our experiments never exceeded 50kg of elemental sulphur and 3kg of copper per ha per year, applied in a maximum of 12 treatments per season. These amounts of fungicides are less than 50% below the amounts usually used to control apple scab in organic production under humid climate conditions (Holb *et al.*, 2003). The 'during-infection' spray strategy has several important advantages compared with the preventive (before rainfall) spray strategy; these include (i) reduced washing effect from the rain, (ii) greater treatment effectiveness on germinating spores, (iii) avoidance of unnecessary treatments and (iv) the ability, in hot seasons, to apply treatments during less sunny periods. The fungicide doses and frequencies used in this study are not phytotoxic, do not adversely affect yield and do not leave undesirable residues on fruits and soils (Jamar, 2011).

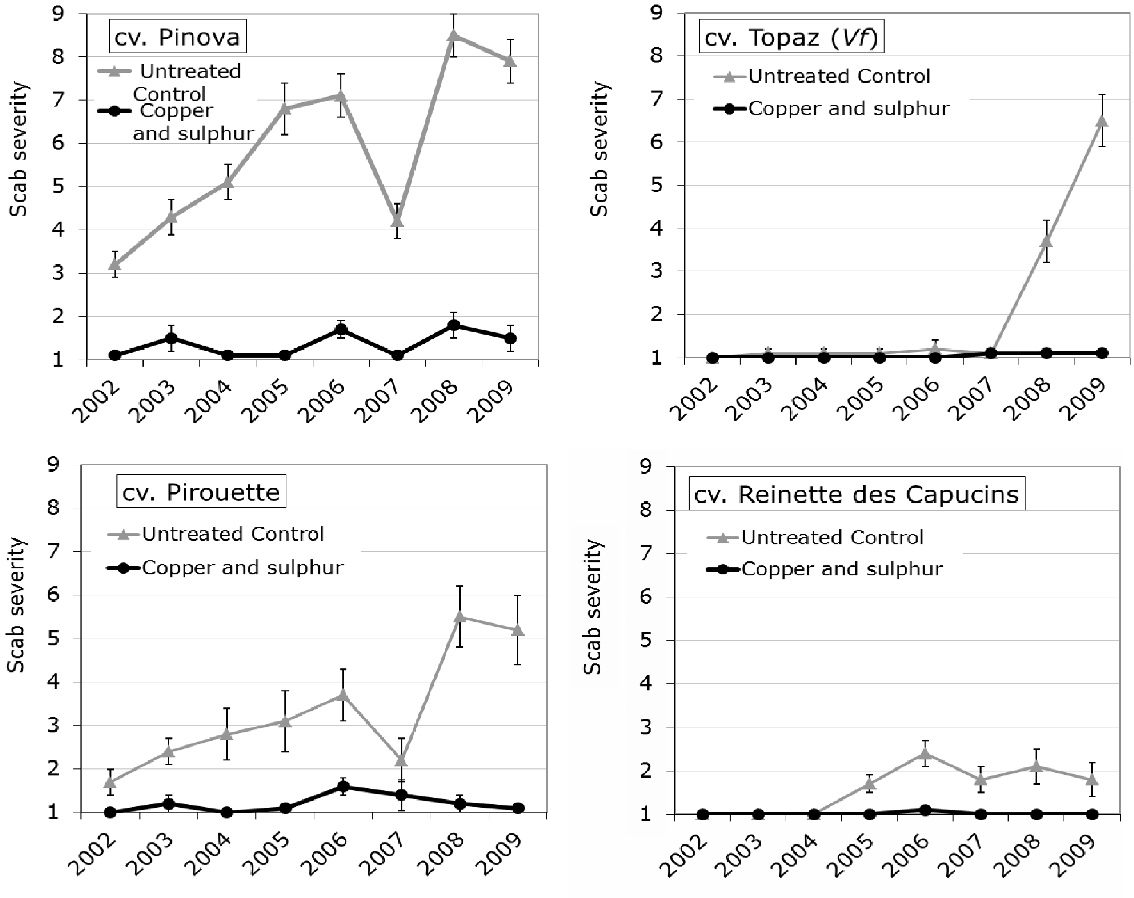

Figure 2: Overall scab severity on leaves assessed 60 days after flowering (1-9 scale), subjected to copper and sulphur spray treatments (CS) compared with the untreated controls (UC) from 2002 to 2009. Error bars denote standard error of the mean ($n = 6$).

Effects on yield

This 8-years study shows that in the organic orchard, an accurate fungicidal protection enhances significantly the yield of the susceptible, and in minor extend, of the polygenic scab-resistant cultivars compared with the untreated control (Figure 3). This suggests a lower long term dependence toward the phytosanitary protection for the polygenic scab-resistant cultivars, in the context of high disease pressure. In the case of monogenic *Vf* scab-resistant cultivars, the dependence toward phytosanitary product seems to reach the scab-susceptible cultivar one when the breakdown of the resistance occurs (Figure 2 and 3). These experiments also reveal the potential of the "during-infection" spraying, using low rate of elemental sulphur and copper, as a protection strategy against scab, in organic or low-input farming, adapted for the most cultivar profiles (Jamar *et al.*, 2010b). With regard to the very low scab-susceptible cultivar cv. 'Reinette des Capucins', which contains polygenic resistance traits, sprays based on sulphur and copper led to a significant increase in yield per tree, especially in the years with high scab pressure (2005, 2006 and 2008) (Figure 3). Such positive effects on yield cannot be explained by the control of apple scab or other apple diseases such as powdery mildew (*Podosphaera leucotricha*), because in all years the infection levels in untreated plots were very low, even at a later stage. The application of elemental sulphur to crops is increasingly advocated as a way of overcoming deficiency in this key nutrient, and sulphur deficiency has recently become a widespread nutrient disorder in crops, largely due to the reduced rate of fossil fuel burning (Jamar, 2011).

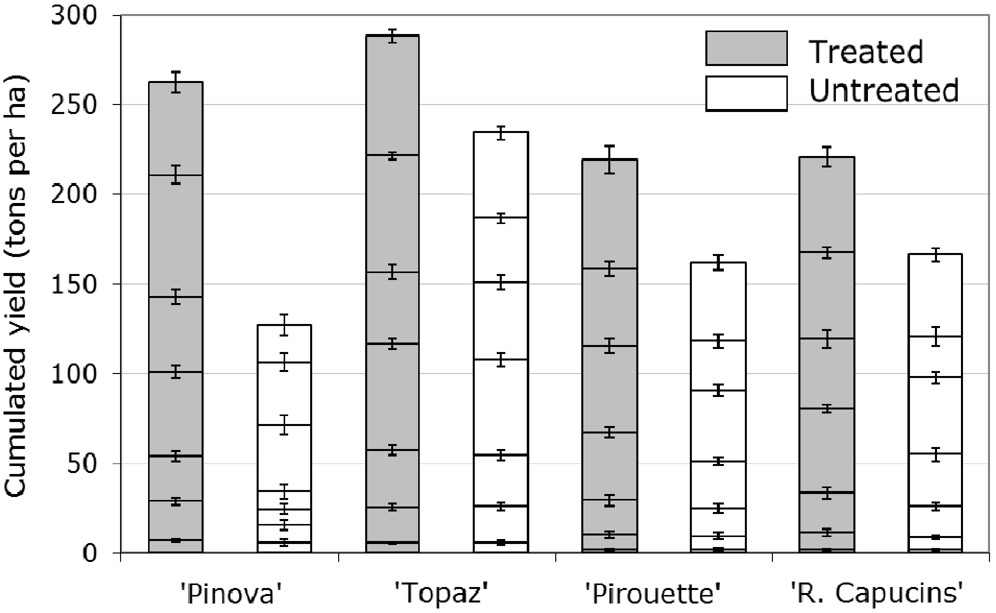

Figure 3: Effect of 8-12 annually "during-infection" treatments against scab on yield from 2002 to 2009 compared with the untreated control in the experimental organic orchard in Gembloux Belgium, planted in 2002 on dwarfing rootstocks in a single row system (3.5 x 1.5m), for a scab-susceptible cultivar 'Pinova', a monogenic *Vf* scab-resistant cultivar 'Topaz', and two polygenic scab-resistant cultivars 'Pirouette' and 'Reinette des Capucins'. Tree density was 1900 trees ha^{-1} in blocks or 1500 trees ha^{-1} in orchards, including 20% of ecological zones. Yield was calculated on the base of 1900 trees ha^{-1}. Errors bars indicate the standard errors of the mean (n = 6; Jamar *et al.*, 2010).

Scab-resistance durability

Based on the apple scab symptoms present in the untreated plots, the following susceptibility ranking for the cultivars could be proposed : high scab-susceptible cultivars for cvs. 'Pinova', 'Initial', 'Zvatava' and 'JN 20/33/58'; medium scab-susceptible cultivars for cvs. 'Pirouette' and 'Topaz'; and low scab-susceptible cultivars for cvs. 'Reinette Hernaut' and 'Reinette des Capucins'. Only the polygenic resistance cultivars showed long-term scab resistance. From 2008, scab infections were very severe on all untreated *Vf* scab-resistant cultivars plots, indicating that the *Vf* major gene protection had been completely broken down by new virulent races. In 2008, cv. 'Topaz' was the only cultivar that still expressed good residual resistance after the *Vf* gene breakdown (Figure 2). Under our experimental conditions, the scab-inoculum pressure increased artificially from year to year, which could have resulted in the presence of untreated control plots randomly distributed in the orchard since 2002.

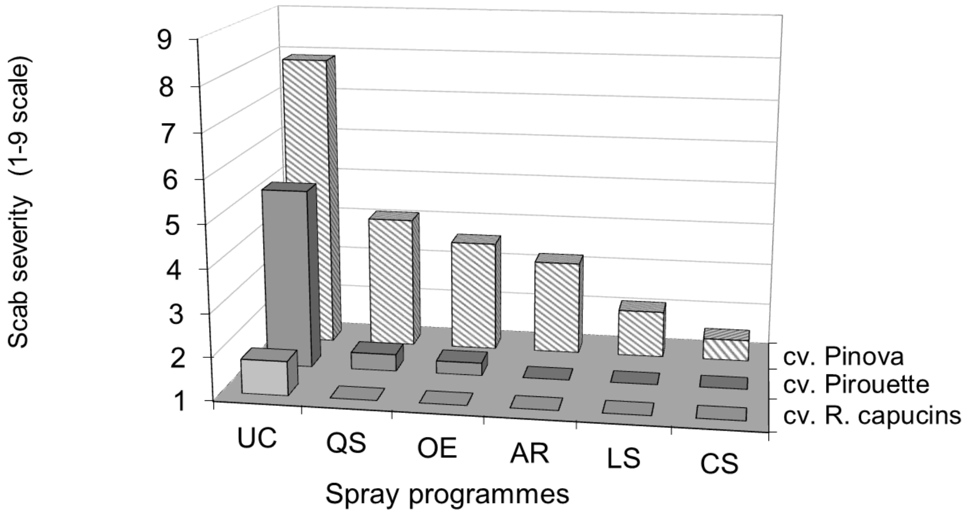

Figure 4: Effect of spray programme on the overall scab severity on leaves assessed 60 days after flowering (1-9 scale) in 2009, on cvs. 'Pinova', 'Pirouette' and 'Reinette des capucins'. Each spray program includes 3 copper treatments (Kocide WG 0,16%) before flowering, excepted the LS. UC = Untreated control, QS = Agri QL 35 (*Q. saponaria* extract), OE = Prev B2 (orange peel extract), AR = Armicarb + Thiovit, LS = Lime sulphur Polisenio, CS = Kocide WG + Thiovit.

Replacement of copper for scab control

Greenhouse experiments conducted on seedlings under controlled conditions showed that, among the 60 products tested, several alternative products reduce significantly scab infection: Armicarb$^{®}$100 (US potassium bicarbonate formulation) (Jamar *et al.*, 2007), Quiponin or Agri QL 35 (*Quillaja saponaria* extract), lime sulphur (calcium polysulfide), Prev-B2 (orange peel extract), Citripur (grapefruit seed extract), Norponin (*Yucca schidigerra* extract), Teawet TQ (*Camellia oleifera* and *Chenopodium quinoa* seed extract). The field study showed that some of them, especially potassium bicarbonate and two plant extracts, have the potential, in combination with other compounds, to reduce copper and sulphur treatments during both the primary and secondary scab seasons (Figure 4). Potassium bicarbonate significantly reduces apple scab and is, in some cases, as effective as wettable sulphur. The use of lime sulphur can significantly reduce or suppress the copper used in a spray treatment based on a 'during-infection' spray strategy. In addition, the amount of copper used for scab control could be significantly reduced for medium and low scab-susceptible cultivars compared with high scab-susceptible cultivars (Jamar, 2011). The lime sulphur treatment can be as effective as the combined wettable sulphur and copper treatment; and also is more effective than wettable sulphur used alone, confirming the results of previous studies (Holb *et al.*, 2003).

Impact of treatments on the predatory mite population

The absence of the phytophagous mite *P. ulmi* and the very low density of *A. schlechtendali* during all the growing seasons in the experimental organic orchard could be associated with the very high density of the predator *T. pyri* observed throughout the orchard. A slight and temporary reduction of *T. pyri* on treated plots in June might be correlated with periods with higher treatment frequencies (Jamar *et al*, 2008).

Using the tunnel sprayer for treatment applications

The use of tunnel sprayers should be encouraged because they can potentially reduce pesticide input and drift in orchards. A recovery system that included a continuous recycling process in the tunnel sprayer led to saving an average of 30% of the applied spray mixtures (Jamar *et al.*, 2010a). Apart from environmental concerns, the benefit of tunnel sprayers would be to reduce plot size in treatment trials using complex experimental designs following the EPPO guidelines. The study showed that, in comparison with the standard axial fan sprayer, the tunnel sprayer produced an equivalent spray deposit in all areas of the trees, with the hydraulic hollow cone (ATR) nozzles, which produce small droplets. Consequently, the general performance obtained in this study cannot be attributed to the specific characteristics of the tunnel sprayer.

Impact of organic farming on some soil bio-indicators

Positive effects on microbial and earthworm communities were observed in the organic orchard in comparison with the conventional one (Jamar, 2011). These positive impacts on soil bio-indicators might have a favourable effect on the performance of important soil functions (Brussaard *et al.*, 2007). Only additional experiments will help to clarify the real impact of farming practices on soil fertility and sustainable crop production. On the basis of the present findings, organic management systems seem the best farming approach for maintaining soil quality with regard to biological indicators (Jamar, 2011).

Fertilization, vegetative growth and scab-susceptibility

In our experiments, annual nitrogen fertilization was maintained from 50 to 60U ha^{-1}, only from organic sources, in order to maintain a balance between vegetative growth and fruiting (Jamar *et al.*, 2010b). Trees were grown vigorously until the canopy fills the allotted space. Thereafter, lower nitrogen fertilizations were applied to keep the trees calm with a balance between vegetative growth and fruiting. The fertilization rates were kept compatible with the pruning system, tree training, tree spacing, soil feature, rootstock and cultivars. The Swiss 'sandwich' system, involving a clover strip below the tree rows, was successfully adopted during the first 3 years. Many mature high-density orchards receive excessive nitrogen fertilizer rates, which cause severe canopy management problems. Heavy nitrogen fertilization supports tree and fruit growth and therefore is a prominent controlling tool for yield. An enhanced vegetative growth of apple trees, however, is often correlated with an increasing susceptibility to pathogens such as *V. inaequalis* (Leser and Treutter, 2005).

Orchard biodiversity and pest management

During this study, mainly focused on the effects of scab control strategies, it was imperative to keep all other pests and diseases below a damage threshold, in order to limit interference on the yield and the productivity. The codling moth (*Cydia pomonella*) and the rosy apple aphid (*Dysaphis plantaginea)* are the biggest pests in apple orchard throughout the world. In our experimental orchard, the codling moth was easy controlled by the confusion method. Very little rosy apple aphid damage was observed throughout the orchard's life; even if none insecticidal treatments were applied during this period. The control of the rosy apple aphid seems to be achieved by the abundance of predatory fauna present in the orchard, likely related with the presence of 20% of ecological zones situated inside the orchard, between experimental blocks (Jamar, 2011). Besides, optimal nutrient and mineral balance in plants could affect the performance of the aphids as suggested below. However, a recent literature review (Simon *et al.*, 2010), show that the effects of the manipulation of plant diversity and habitats on the control of pests by arthropod and bird communities in apple orchards were mostly positive (55% cases), or null (30%), but also negative in some cases (15%). This finding reveals the difficulties of identifying selected plants assemblages for the control of key pests and choosing the optimal orchard design for organic or low-input system. A reduced use of pesticides could lead to the resurgence of secondary pests (Wateau *et al.*, 2011)

Conclusions and prospects

This long-term field study clearly showed that the 'during-infection' spray strategy allows a reduction in the use of fungicides for primary scab control. Combining multiple factors such as planting cultivars with more durable resistance to scab, planting mixed cultivars in higher functional diversity orchards, and increasing the emphasis on culturally based practices aimed at reducing initial inoculum, coupled with an accurate spray strategy in spring as defined in the present study, are the most likely approaches for substantial further reductions in fungicides and for sustainable fruit production that is acceptable to consumers and fully compliant with organic crop production standards.

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