Biodiversity and pest management in orchard systems. A review

Sylvaine Simon, Jean-Charles Bouvier, Jean-François Debras, Benoît Sauphanor

Agron. Sustain. Dev. 30 (2010) 139–152
© INRA, EDP Sciences, 2010
DOI: 10.1051/agro/2009013

Available online at:
www.agronomy-journal.org

Review article

Biodiversity and pest management in orchard systems. A review

Sylvaine SIMON[1]*, Jean-Charles BOUVIER[2], Jean-François DEBRAS[2], Benoît SAUPHANOR[2]

[1] INRA, UERI, Gotheron, 26320 Saint-Marcel-lès-Valence, France
[2] INRA, UR1115 Plantes et systèmes de culture horticoles, 84000 Avignon, France

(Accepted 29 April 2009)

Abstract – Conventional agriculture is based on a high level of chemical inputs such as pesticides and fertilisers, leading to serious environmental impacts, health risks and loss of biodiversity in agrosystems. The reduction of pesticide use is a priority for intensively sprayed agricultural systems such as orchards. The preservation and promotion of biodiversity within orchards and their boundaries is therefore an issue to explore. Indeed, orchard systems contain high plant diversity and perennial multi-strata designs that provide wealthy resources and habitats to living communities such as beneficial organisms. Orchards thus offer favourable areas to maintain food-webs within the agrosystem, provided that favourable situations are not altered by cultural practices such as applying an excess of pesticides. Here, we analysed literature on the effects of the manipulation of plant diversity and habitats on the control of pests by arthropod and bird communities in apple, pear and peach orchards. Many investigations focus on the role of plant management to enhance biodiversity in orchards but only 22 research reports presenting 30 case studies were dedicated to the study of the ecosystem service provided by plant diversity for orchard pest control. The underlying mechanisms were seldom demonstrated, and the tested grass covers and tree assemblages aimed at favouring either the beneficial complex or only some beneficial species to control one or a few pests. The effect of plant management on pest control was mostly positive (16 cases) or null (9), but also negative in some cases (5). This finding reveals the difficulties of identifying selected plants or plant assemblages for the control of key pests. We conclude that further research is needed to identify the processes involved on different scales for biological control. Orchard systems should be re-designed to optimise ecosystem services provided by biodiversity.

biodiversity / orchard / fruit tree / plant / arthropod / bird / community / pest management / hedgerow / plant cover

1. INTRODUCTION

Since the 90s and the Rio summit on biodiversity in 1992, there has been increasing concern about the environment, and a consciousness of the impact of production and service human activities on the environment and on biodiversity. Conventional agricultural production which is based on a high level of chemical inputs, e.g. pesticides and fertilisers, is in the focus. Political actions at national and European Community levels aim at reducing the number and amount of pesticides used (PIRRP, 2006; Commission Européenne, 2008), and to promote research programmes to reduce their use or the risks due to their use (Aubertot et al., 2005; Sauphanor et al., 2009). Indeed, many environmental risks are related to the use of conventional insecticides, e.g. their aerial dissemination and the contamination of soil and water, with negative effects on animal communities directly or indirectly exposed to these chemicals (Aubertot et al., 2005), and on human health (Baldi et al., 1998). Moreover, besides the loss of habitats, pesticides also contribute to the decrease in plant and animal biodiversity in the agrosystem (Krebs et al., 1999). Reduction in the use of plant protection products is thus crucial for the implementation of sustainable agricultural systems, and especially in systems based on a high pesticide use such as orchards. Indeed, in temperate areas, orchards are among the most intensively sprayed agricultural systems to impair pest and disease damage and produce fruits with no visible fault to satisfy international commercial quality standards. Whereas French orchards only represent 1% of the utilised agricultural area, they make up 21% of the insecticide sales in France (Codron et al., 2003). Recently, information on the pesticide residues in fruits has altered the perception of fruits by consumers as fresh and healthy food, leading in several countries to the implementation of zero residue programmes (Berrie and Cross, 2006). There is thus a challenge in satisfying a societal demand for environmentally friendly systems and healthy fruits, and keeping pests and diseases below economic thresholds to maintain the growers' income in an evolving regulation context. The preservation and promotion of biodiversity within agricultural landscapes could be a key issue to answer both ecological and agronomic purposes.

Cultural systems have, on different scales, a dualistic relationship with biodiversity. They often reduce, or alter,

* Corresponding author: sylvaine.simon@avignon.inra.fr

Article published by EDP Sciences

Table I. Contribution of annual and orchard systems to plant biodiversity.

Plant diversity provided by the agrosystem	Annual systems	Standard orchard systems
Diversity in time	Crop rotation: turnover of host plants	Perennial crop: permanency of host plants
Diversity in space:		
- Plant architecture	-	Fruit tree complex branching structures
- Spatial distribution of plants within the field	Homogeneous plant cover and mono-stratum systems	Heterogeneous distribution (fruit tree rows, alleys) and multi-strata (arboreal, understorey) systems
- Adjacent diversity	Large fields adapted to machinery	Need for windbreaks in windy regions: planting of lining hedgerows

biodiversity through simplified systems or cultural practices. However, cultural systems also contribute to the agrosystem richness and to the occurrence of some plant and animal species that would otherwise have disappeared (Le Roux et al., 2008). Besides, cultural systems are dependent on several ecosystem processes provided by biodiversity that contribute to soil fertility, pollination and pest control (Zhang et al., 2007). If there is a consensus on the role of ecosystem services for crop production, then strategies to maintain, favour and preserve biodiversity are more debated. These strategies can range from surface areas dedicated to biodiversity conservation ('land-sparing agriculture') to biodiversity preservation within agricultural areas ('eco-friendly agriculture') (Clergue et al., 2005). Agroecology (Altieri, 1995) represents the challenge to match production and biodiversity conservation within agricultural landscapes, especially in areas where cultivated lands occupy a large surface area.

Among cultivated crops, orchards are particularly suitable systems to study the level of ecosystem services provided by biodiversity, because they are perennial systems and present a complex multi-strata design. In most European orchards, plant components associated with fruit trees are planted and/or preserved and managed within orchards and/or in their boundaries for agronomic purposes, e.g. prevention of soil compaction due to machinery traffic, windbreaks and physical barriers. Orchard plant design thus contributes to plant diversity within agricultural areas and therefore to an increase in resources for animal communities such as arthropods and birds (Boller et al., 2004), among which are pest antagonists, provided that cultural practices, namely pesticide use, are not disruptive. Moreover, the importance of the ecosystem service provided by natural enemies for pest control has been pointed out for decades in orchards, with a focus on the control of many fruit pests such as mites, aphids, leafminers and psyllids by natural enemies (e.g. Wildbolz, 1988; Boller et al., 2004). The key role of natural enemies has been demonstrated for psyllids in pear orchards (Shaltiel and Coll, 2004) and mites in apple orchards (Solomon et al., 2000). There is thus a need to evaluate in orchards the role of functional diversity, i.e. the ecosystem service for pest control, but also the importance of disservices due to agricultural and ecosystemic management (Zhang et al., 2007).

The aim of the present review is to analyse the complex relationships between orchard systems, i.e. orchard design and practices, and functional biodiversity with a focus on plant, arthropod and bird communities. Our work is based on a thorough investigation of the ISI Web of Knowledge database from 1992 to January 2008, and on former articles cited in this literature, complemented by recently accepted articles. Orchards were considered to be agricultural surface areas dedicated to fruit production, which excluded several types of agroforestry or pastoral systems planted with fruit trees. Only pome and stone fruit productions in temperate areas were studied. Lastly, biodiversity was defined according to Noss (1990) and comprised compositional, structural and functional biodiversity on different scales. We develop two main points: (i) the contribution of orchard systems to plant and animal diversity against adverse effects of orchard practices on biodiversity, and (ii) the benefits for the orchard pest management of biological control through the conservation of habitats.

2. ORCHARD SYSTEMS AND BIODIVERSITY

The potential contribution of orchard systems to biodiversity is based on the analysis of their main specific features: permanency of the system, multi-strata design and adjacent plant management (Tab. I) as favourable aspects, and the need for intensive pest management, including a recurrent use of pesticides, as a detrimental factor.

2.1. Perennial habitats

Orchards are planted for several years or even decades in temperate areas: the diversity in time due to the successive crops of the cultural rotation is thus low in orchard systems. However, such a permanency in the host plant and the associated cultural practices is likely to enhance the stability of the system (Brown and Welker, 1992) and its resilience (Kozár, 1992). The permanency of the host plant favours the presence of some herbivores (which include pests) to the benefit of the permanency of food-webs. The entomofauna richness measured in apple orchards is higher than in annual crops in Hungary (Kozár, 1992), and the control provided by the natural enemies of pests is also reported to be higher in perennial than in annual crops (Hall and Ehler, 1979; Risch et al., 1983). Food and living conditions in organic apple orchards are favourable to the presence and the nesting of insectivore birds such as the Great Tit *Parus major* (Paridae), with reproduction rates equal to that of pesticide-free forests (Bouvier et al., 2005). Lastly, the soil litter is also likely to develop, to the benefit of the scavenger biomass which favours the abundance of some natural enemies (Longcore, 2003). As permanent habitats, orchards therefore contribute to the presence of a diversified arthropod community including scavengers, herbivores, predators and parasitoids, and to the permanency of food-webs including high trophic levels, namely, the insectivorous bird community.

2.2. Multi-strata habitats

In most cases both understorey and arboreal habitats are present within orchards. A grassy ground cover is generally sown or naturally occurs between rows and in the turning ends of the orchard to prevent soil compaction by machinery traffic, to limit erosion and/or pesticide transfer (Lacas et al., 2005). The arboreal habitat mainly consists of planted fruit trees. Various species of arthropods can live in one or more of these strata. The surface area of the orchard thus consists of a meadow interplanted with fruit tree rows where the soil arthropod community is more related to that of a meadow than of a forest (Fazekas et al., 1992). The effect of the orchard plant design on arthropod diversity is analysed on different spatial scales: (i) arboreal strata and within-tree structure, (ii) additional grass cover as understorey strata, and (iii) orchard system.

Fruit trees have a characteristic architecture, partly due to tree-training performed to ensure regular fruit bearing. Indeed, branching structures of the branches and patterns of distribution and growth of fruiting and vegetative shoots contribute to a complex within-tree architecture. Moreover, different scales, including leaf structure and infra-structures such as domatia and trichomes (Cortesero et al., 2000) are present. This structural complexity favours the richness of the entomocenosis (Price et al., 1980; Lawton, 1983) and the abundance of natural enemies (Langellotto and Denno, 2004; Finke and Denno, 2006). Even though underlying processes affecting tree arthropods within complex structures are not always disentangled by authors the most plausible are: (i) the diversity of plant resources benefits specialised herbivores which are the prey or the host of various natural enemies, being themselves the prey or host of other predatory or parasitoid insects; and (ii) intra-guild predation decreases in complex structures (Finke and Denno, 2006) and 'enemy-free spaces' are more important (Lawton, 1983). The structural complexity and heterogeneity of the fruit tree thus favours the diversity of the canopy arthropod community. However, complex structures are also detrimental to the foraging of some beneficial insects, through an increase in the time needed to locate their prey or host (Gingras and Boivin, 2002; Skirvin, 2004). Consequently, pest control through parasitism or predation is not always higher in complex than in simpler structures despite higher entomological diversity or abundance (Langellotto and Denno, 2004; Simon et al., 2007a).

As additional plant strata to productive trees, the plant cover in the alleys is generally composed of grasses (Poaceae), mixed with weeds and sometimes with other sown species such as leguminous plants. The presence of an understorey cover generally provides a benefit for the orchard pest control. A three-species plant cover sown in the alleys provides a higher richness and diversity of the pear canopy entomocenosis compared with a bare ground (Rieux et al., 1999). The beneficial aphidiphagous complex of the apple orchard is favoured by flowering strips to the benefit of aphid control (Wyss, 1995). Plant covers are only reported to be detrimental compared with a bare ground in peach orchards where they favour leafhoppers (McClure et al., 1982) and phytophagous mites (Meagher and Meyer, 1990a).

The co-existence of different strata creates a diversity of habitats and resources for animals: shelters, e.g. resting, diapause or hibernating sites, reproduction areas and refuge areas to escape disruptive agricultural practices, as well as food, e.g. alternate preys and hosts, nectar and pollen (Greaves and Marshall, 1987). Arthropod communities exploiting the soil, the grass and the canopy (Miliczky et al., 2000) cohabit within the orchard and contribute to its richness. Some species are likely to exploit more than one of these strata and are therefore likely to stay and multiply through higher levels of resources. As high levels of beneficial arthropod richness are displayed within the grass cover, whereas low levels of predation and pest control are observed within the arboreal strata (Simon et al., 2007b), strong interactions among strata are not always established in field experiments. The hypothesis of a structural rather than a functional assemblage is promoted by some authors (Vogt et al., 1998; Miliczky et al., 2000; Horton et al., 2002; Simon et al., 2007b). It cannot be excluded that the beneficial complex of the fruit tree canopy does not benefit the grass cover richness or diversity. Although the intrinsic complexity of fruit trees and the diversity in resources provided by the orchard plant design are high, the resulting arthropod diversity is not always highly functional for pest control.

2.3. Plant diversity in the boundaries of orchards

As fruits are delicate high value products and orchards perennial systems, they easily support the installation of windbreaks in windy regions (Prokopy, 1994). The most common ones are planted hedgerows. Some of the planted hedgerows in the orchard boundaries are multi-species hedgerows, for instance, composed after the recommendations by the IDF (Institut pour le Développement Forestier, 1981). As the diversity of planted fruit species or cultivars is low within the orchards, e.g. the most common cases are one or a few clones, these hedgerows improve the orchard system plant diversity. Although hedgerows may impair crop protection by harbouring potential pests and diseases (Solomon, 1981; Jeanneret, 2000), they are also physical barriers that stop drifts from adjacent pesticide applications and thus minimise side effects of pesticide use. If the hedgerow contributes by itself to the local plant biodiversity through the same mechanisms as plant covers, the association of orchards and hedgerows within the landscape creates and favours specific habitats and ecosystems. This contributes to the increase in global and landscape biodiversity (Pollard and Holland, 2006). A mosaic landscape consisting of orchards separated by hedgerows and/or ditches favours a specific flora and fauna through a higher availability of habitats and resources (Rands, 1986). Such areas are also hibernating sites for many insect species (Harwood et al., 1992; Lys and Nentwig, 1994). The communities of both adjacent plantings and local surroundings interfere with the orchard (Krebs et al., 1999; Simon, 1999; Benton et al., 2003). On a local scale, the biodiversity of the orchard system is improved by lining hedgerows and ditches (Green et al., 1994; Parish et al., 1994; Moles and Breen, 1995), as the biodiversity on the landscape scale is improved (Benton et al., 2003) through an increase in available biotopes (Rosenzweig, 1995). This latter aspect is especially emphasised for mobile taxa such as Lepidoptera (Jonsen and Fahrig, 1997) and birds (Robertson et al., 1990). Orchard systems and their boundaries are thus highly relevant candidates to contribute plant and animal diversity on different scales.

However, it is necessary to minimise such potentially favourable situations: the widespread use of the mating disruption method to control Lepidoptera requires large surface areas without interplanted hedgerows (Witzgall et al., 2008; Sauphanor, in press). Italian and Northern American studies (Neumann, 1993) indicate an optimal efficiency for continuous surface areas of homogeneous orchards of tens of hectares protected by this method, which favours pheromone diffusion and minimises the vulnerability of borders. A recent study (Ricci et al., 2009) also indicates that the codling moth *Cydia pomonella* populations of a given orchard are negatively correlated with the surrounding surface areas planted with apple and treated with chemicals, which promote the production of apples within large surface areas whatever the pest control method (if efficient) against codling moth. The planting of large surface area orchards excluding hedgerows, which are replaced by hail nets as windbreaks and shields for the physical control of *C. pomonella* and tortricids (Tasin et al., 2008), are likely to develop in Southern France. There is an antagonism between the optimal use of various pest control methods and the management of plant diversity in the boundaries of the orchard system.

2.4. Pesticide applications

Because of their host-tree permanency pests and diseases may remain present in the orchard throughout the year. This favours the increase in infestation or infection levels from one year to another, with the need for a continuous protection, namely, a recurrent use of pesticides to control them. Fruit tree protection is highly intensive and requires far more pesticide amounts than other crops. In 2006, an average of 36.5 treatments were sprayed in French apple orchards (Sauphanor et al., 2009). In all producing countries, current apple production systems resort to such intensive use of pesticides (Eurostat, 2002). Moreover, the trend is for an increase in the yearly number of treatments because of the development of resistant strains in some pests (Sauphanor et al., 2000; Reyes et al., 2008), low surface areas planted with resistant or low-susceptibility cultivars, and 'zero default fruit' market standards. Global warming is also likely to increase voltinism and the period of risks for some pests (Sauphanor, 2004), and to introduce new pests. From green tip to harvest, i.e. during a 6- to 8-month period, apple orchards are thus under pest and disease management regimes based on the use of pesticides. The side effects of their use on organisms living or foraging within the orchard may be direct through mortality and/or lower fecundity, or indirect through biomass (i.e. prey or host) reduction or host-plant suppression in the food-web.

In orchards the effect of pesticides and pest management regimes on arthropods is well documented for a few taxonomic groups, amongst which are spiders (Pekár, 1999; Bogya and Markó, 1999; Bogya et al., 1999; Miliczky et al., 2000; Brown et al., 2003) and ground-living beetles (Pearsall and Walde, 1995; Labrie et al., 2003) but it is more seldom studied for the total arthropod community (Sauphanor et al., 1993, 2005; Suckling et al., 1999; Brown and Schmitt, 2001; Debras et al., 2006; Simon et al., 2007b). The use of pesticides has a negative effect on hunting spiders (Pekár, 1999), ground-living arthropods (Epstein et al., 2000) and insects parasitising leaf miners (Prokopy et al., 1996) but, surprisingly, the total arthropod diversity or richness of the tree canopy is not or very little affected by the use of broad-spectrum insecticide programmes compared with more environmentally friendly methods (Suckling et al., 1999; Brown and Schmitt, 2001; Simon et al., 2007b). Hypotheses that are likely to explain such results may be related to: the resilience of the orchard system (Brown, 1993); a high immigrating rate of arthropods in small-sized orchards within mosaic landscapes (Liss et al., 1986; Whalon and Croft, 1986; Brown, 1993; Kozár, 1992; Bengtsson et al., 2005; Miliczky and Horton, 2005); and/or the inadequacy of synthetic diversity indices to give information on a whole community composed of groups with inconsistent responses (Suckling et al., 1999; Hole et al., 2005). However, even though the diversity measured by classical ecological indices such as the Shannon index is not always affected, the abundance of arthropods is always negatively affected by intensive pest management regimes (Suckling et al., 1999; Brown and Schmitt, 2001; Simon et al., 2007b), as are soil micro-arthropods (Doles et al., 2001).

The structure of the arthropod community also differs among high- and low-intensity pest management regimes (Andreev et al., 2006), and the natural control of some apple pests may be altered under intensive management regimes (Brown and Adler, 1989; Balázs et al., 1996; Suckling et al., 1999; Simon et al., 2007b): the beneficial arthropod complex is thus no longer present for ecosystem services. Enhanced ecosystem services for pest control permitted by a reduction in pesticide exposition such as in organic or low-input orchards illustrate the mutual benefits between conservation biological control and a reduced pesticide use (Sauphanor and Audemard, 1983; Brown, 2001a; Zehnder et al., 2007).

Birds constitute bio-indicators which are used to assess the effect of cultural practices on the environment (Ormerod and Watkinson, 2000). Because they occupy a high or top position in the food-web, they are relevant indicators of its global alterations (Furness and Greenwood, 1993). Besides, some of their biological requirements such as reproduction are concomitant with the period of pesticide applications in fields (Chamberlain et al., 2000). The documentation on the effect of pest management strategies on birds in apple orchards is still incomplete. Most of the studies focus on the reproduction rate of passerine birds, which is lower in intensively managed orchards compared with organic ones, in Northern America (Powell, 1984; Fluetsch and Sparling, 1994; Bishop et al., 2000) as well as in Europe (Bouvier et al., 2005). The effect of pesticides on bird communities is less studied. The bird diversity and abundance in German orchards was higher in organic than in Integrated Pest Management (IPM) orchards (Rösler, 2003). Consistently, the two research teams working on the subject have assessed that bird communities are more abundant and diversified in organic apple orchards, or to a lesser extent in IPM orchards, than in conventional intensive ones where the number of insectivore species is also lower (Bouvier, 2004; Genghini et al., 2006).

Local and regional environments, cultural practices and manipulations of the orchard plant diversity widely interfere. Only a few recent studies (Debras et al., 2006; Agerberg, 2007; Monteiro et al., 2008) have quantified the weight of these external factors. The weight of environmental variables to explain the composition of the orchard arthropod community is 28.7%, whereas it is 12.4% and 2.2% for cultural practices and lining hedgerows, respectively (Debras et al., 2006). For bird communities, both pesticide applications and the local environment account for 25% in the results, whereas the landscape effect contributes 15% to the total variance in apple orchards in Southern France (Agerberg, 2007). This latter result is consistent with the study by Monteiro et al. (2008) on the parasitoid community of pome fruit orchards in Southern France that displayed a similar contribution of local (27%) and landscape (16%) factors. However, further research is needed to validate such results within various contexts and regions, to assess the potential contribution of local and/or landscape diversity to explain the structure of bird and arthropod communities, and to identify local and landscape managements maximising the abundance of natural enemies.

3. BENEFITS OF BIODIVERSITY FOR THE CONTROL OF ORCHARD PESTS

The most studied benefits of biodiversity for fruit tree production are related to crop protection and are mainly based on an increase in plant diversity that favours the increase in animal diversity, including birds, mammals and arthropods. A higher level of pest control is thus expected, at least for some pests, through an increase in the abundance and the richness of their natural enemies. Within this framework of conservation biological control (Barbosa, 1999), we develop the effect on orchard pest control of (i) two plant assemblages associated with the orchard, i.e. plant ground covers and lining hedgerows, and (ii) the local land uses in the agricultural landscape. Lastly, the role of insectivore birds, favoured by nesting-boxes, will be discussed. Diversity is understood as measurements by classical ecological indices such as the Shannon index, but also by richness and abundance of the studied groups. All taxonomic levels are taken into account.

3.1. Manipulation of plant diversity to enhance orchard pest control

The effect of plant diversity on the arthropod populations of pests and natural enemies relies on several complex mechanisms (Russell, 1989): plant-insect relationships, prey-predator and host-parasitoid interactions, population dynamics, and structure and organisation of arthropod communities (Liss et al., 1986). The mechanisms involved are seldom demonstrated by authors. Both bottom-up and top-down effects are promoted to explain a reduced herbivory in complex compared with simple environments (Russell, 1989). The following mechanisms are either simultaneously (Bugg and Waddington, 1994) or individually proposed:

- within a diversified system, the decrease in pest damage is related to greater difficulties in localising their host plant(s) and to lower resources (Risch et al., 1983); structural and chemical complexities of plant assemblages are thus the cause of such decrease in herbivory (Brown, 1998);
- plant associations may alter the microclimate, the physiological stage or even the pest biology, contributing to pest control (Parfait and Jarry, 1987; Andow, 1991);
- due to a diversified vegetation, the predatory and parasitoid complex likely to control pests is maintained and made perennial (Risch et al., 1983; Szentkiràlyi and Kozár, 1991; Chaubet, 1993; Wyss, 1996; Brown, 2001a). The longevity or fecundity of some species may also be increased (Irvin et al., 2006).

The manipulation of the orchard plant diversity may affect communities living within or near the orchard through an increase in the resource range, i.e. habitat, shelter and food. Herbivores, including orchard pests, polyphagous and disease vector arthropods, pollinators, and predatory and parasitoid arthropods are involved, and the manipulation can result in beneficial or detrimental effects for the orchard pest control (Grison and Biliotti, 1953; Van Emden and Williams, 1974; Gruys, 1982; Fye, 1983; Solomon, 1981; Bugg and Waddington, 1994; Prokopy, 1994; Rieux, 1994; Schoemans, 1995; Simon, 1999; Boller et al., 2004; Debras et al., 2007). Very few studies address the economic benefit of such manipulation of plant diversity in the orchard or its boundaries. Besides several studies on the arthropod community of understorey plants (e.g. Westigard et al., 1990; Flexner et al., 1991; Meyer et al., 1992; Coli et al., 1994 on mites), pest control resulting from the introduction of plant assemblages is seldom directly assessed. The results may vary according to the host fruit species, the pest and the tested plant assemblage (Tab. II). Among the 22 listed articles presenting 30 case studies on the subject, the effect on pest control was positive in 16 cases, 5 plant assemblages had a negative effect and 9 others were indifferent. Plant manipulations generally aimed at favouring either predator or parasitoid beneficial taxonomic groups or

Table II. Effects of plant diversity on the control of orchard pests.

Fruit tree production	Target pest(s)	Plant manipulation(s) or presence	Effect on pest control[1]	Source/Region
Apple	Apple aphids *Aphis pomi* *Dysaphis plantaginea*	Flower strips	Positive Positive	Wyss (1995); Wyss et al. (1995), Switzerland
Apple	Apple aphids *D. plantaginea*	Flower strips	Positive	Pfammater and Vuignier (1998), Switzerland
Apple	Apple aphids *A. pomi* *D. plantaginea*	Flower strips Negative	Null	Vogt et al. (1998); Vogt and Weigel (1999), Germany
Apple	Tent caterpillar and codling moth	Understorey plants	Positive Positive	Leius (1967), USA
Apple	Leafroller (Tortricidae)	Buckwheat	Positive	Stephens et al. (1998), New Zealand
Apple	Leafroller (Tortricidae)	Buckwheat Alyssum Phacelia	Positive Positive Null	Irvin et al. (2006), New Zealand
Apple	Leafroller (Tortricidae)	Peach nectaries	Null	Brown et al. (2008), USA
Apple	Apple aphids *Aphis spiraecola*	Peach nectaries Buckwheat	Negative Null	Spellman et al. (2006), USA (greenhouse experiment)
Apple Peach	Apple pests Peach pests	Plant cover and/or interplanted fruit-tree	Null or variable according to years and pests	Brown (2001b), USA
Apple	Apple pests	Plant cover	Null	Jenser et al. (1999)
Apple	Spider mites	Understorey plants	Positive under conditions	Croft B.A. (1982), USA
Apple	Spider mite *Tetranychus* spp.	Understorey plants	Positive under conditions	Alston D. (1994), USA
Apple	Spider mite *Panonychus ulmi*	Plant cover	Null	Nyrop et al. (1994), USA
Apple	Apple pests	Plant cover	Globally positive	Altieri and Schmidt (1985), USA
Apple	Spider mite *P. ulmi*	Adjacent bushes	Positive	Tuovinen (1994), Finland
Apple	Spider mites *Tetranychus spp.*	Plant cover	Positive	Yan et al. (1997), China
Apple Pear	Spider mite *P. ulmi* *Cacopsylla pyri*	Flower plant mixture	Null Null	Fitzgerald and Solomon (2004), UK
Peach	leafhoppers	Plant cover	Negative	MacClure et al. (1982), USA
Peach	Spider mite *T. urticae*	Plant cover	Negative	Meagher and Meyer (1990a), USA
Peach	Hemiptera species	Plant cover	Negative	Meagher and Meyer (1990b), USA
Pear	*C. pyri*	Plant cover	Positive	Rieux et al. (1999), France
Pear	*C. pyri*	Hedgerow	Positive	Debras (2001, 2007), France

[1] The effect of plant manipulation on pest control is considered to be positive, null or negative when either the density of the pest arthropod of the fruit tree, fruit damage and/or the number of pesticide applications against the target pest is lower, equal or higher, respectively, compared with control.

species. The total beneficial complex is more seldom targeted. Most of the plant manipulations were based on the manipulation of understorey plants or plant assemblages, or on the analysis of naturally occurring plant ground covers. Only two of them were related to arboreal plant assemblages (adjacent bushes or lining hedgerows), attesting to the difficulties of carrying out field experiments on perennial plant assemblages. With the exception of one case in orchards, i.e. the detrimental effect of flower strips on apple aphid (Vogt and Weigel, 1999), negative effects were mainly due to the development in weeds of spider mites migrating into fruit trees when weeds are chemically or mechanically removed.

Several aspects can explain such variability in the results: the studied "pest-antagonist" couple, local context, composition, age and management of the tested plant assemblage, and orchard design. Cultivar and age of producing orchards are reported to be of little importance to explain the structure of the orchard arthropod community, providing the cultivars are not insect-resistant and tree architecture is similar (Brown and Adler, 1989). Only juvenile orchards, which are seldom experimented on, differ from older ones (Pekár, 2003). More generally, the effect of a plant manipulation largely relies on the biology of each targeted pest and each natural enemy, and on their interactions, between them and with other species of the arthropod community. We present below understorey and arboreal plant manipulations dedicated to enhancing pest control in orchards. Only plant-based approaches were considered. The manipulation of the habitat of ground-dwelling arthropods, for instance, by mulching the groundcover (Miñarro and Dapena, 2003; Mathews et al., 2004) was not reviewed.

3.1.1. Lining hedgerows

Hedgerows lining the orchard are plant assemblages comprising tree species that may constitute a reservoir, or a source, of natural enemies, and also the source of infestation or infection by pests and diseases (Solomon, 1981; Prokopy, 1994; Schoemans, 1995; Maudsley, 2000; Boller et al., 2004). Studies or reviews on the specific entomocenosis of many tree species planted in hedgerows are available in Southern France (Barthelet, 1982; Defrance et al., 1987; Campo, 1992; Carraretto, 1992; Gauthier, 1993; Simon et al., 1993; Rieux, 1994; Delmas, 1995; Sarthou, 1995; Reboulet, 1996; Simon, 1999; Baudry et al., 2000; Debras, 2001; Debras et al., 2002), but precise and comprehensive information is still missing because of local specificity, climatic variations and time-consuming assessments by experts trained in arthropod systematics.

Very few hedgerows dedicated to crop protection have been experimented on. The mixed hedgerow proposed by Rieux (1994) for the control of the pear psyllid *Cacopsylla pyri* in pear orchards and experimented on since 1992 in Southern France has been built up according to the following principles and experimentally assessed (Simon et al., 2009):

- exclude tree species hosting orchard or quarantine pests and diseases, i.e. hawthorn, which is the host of fireblight;
- provide some natural enemies, i.e. the one(s) active against the main orchard pest(s) with various habitats and resources: shelter, hibernating site, and areas to escape within-crop cultural practices. These consist of hollow stems of herbaceous plants, bark crevices, evergreen leaves of bush or tree species, intertwine stems of creeping species; food such as pollen, nectar, alternate preys or hosts;
- organise all year long successive resources in order to maintain and multiply beneficial arthropods in the vicinity of the orchard;
- favour the motion of natural enemies from the hedgerow towards the orchard, using tree species hosting migrating alternate preys which induce natural enemies to search for new preys.

The presence of natural enemies is generally higher in the part of the orchard lining the hedgerow than in its centre (Altieri and Schmidt, 1986; Reboulet, 1996; Paoletti et al., 1998) and aphid abundance is correlatively the lowest in orchard edges where beneficial numbers are the highest (Altieri and Schmidt, 1986). A gradient of density from the hedgerow towards the orchard is described for lacewings (Rodet, 1985; Simon et al., 1998). Earwigs issuing from the hedgerow are collected within the orchard in Southern France (Debras et al., 2007). Debras (2007) and Debras et al. (2008) also assessed that the distribution of natural enemies within the orchard is affected by the hedgerow: natural enemies actively move from the hedgerow to the orchard in relation to prey availability, even though cultural practices (among which the use of pesticides) alter this functional pattern in most orchards. However, a significant effect of the hedgerow on the orchard beneficial complex is not always displayed. Coli et al. (1994) did not relate high densities of predatory mites hosted by bush species to mite populations of the adjacent orchard. As an adverse effect, codling moth abundance was observed to be the highest along the hedgerow (Audemard, 1992). Lastly, no significant correlation was displayed between predator abundance due to plant environment and *C. pyri* control in a survey of 8 commercial pear orchards (Simon, 1999). Patterns of pest distribution and patterns of predator densities introduced by the plant environment are thus not always correlated. Such discrepancies may be explained by the thermal and biological requirements of the considered arthropod species and by the climatic effect of the hedgerow on the distribution of both pests and natural enemies (Debras et al., 2008; Ricci et al., 2009). Lastly, the age (Burgio et al., 2006) and the cultural management of these hedgerows may alter their structural and plant diversity, therefore altering their functionality (Forman and Baudry, 1984). The benefit of the increase in the abundance and diversity of natural enemies induced by plant manipulation is, however, seldom measured; the benefit, if any, can be slight, and not sufficient to avoid pesticides against the most noxious pests. We noticed that only pests such as mites and psyllids, which can be tolerated at high population levels in the orchards, may benefit from such manipulations (Tab. II). Beyond short-term pest control, the recolonisation of the orchard by natural enemies issuing from adjacent plant assemblages can contribute to the restoration of the community structure (e.g. the case of mites, see Tuovinen, 1994) and to a more stable system.

3.1.2. Plant ground covers and interplanted fruit tree species

A wide range of plant covers and interplanted peach trees (Brown, 2001b; Brown et al., 2008) were tested by the authors (Tab. II). Most of the tested assemblages aimed at providing beneficial arthropods with pollen and nectar through flowers or peach nectaries. Grassy or flower strips sown in the orchard alleys (between rows) are proposed in apple orchards to help control the rosy apple aphid *Dysaphis plantaginea* (Wyss, 1995; Wyss et al., 1995; Pfammatter and Vuignier, 1998; Vogt et al., 1998). Single species covers with buckwheat, phacelia or alyssum were experimented on in New Zealand to help control Tortricidae (Stephens et al., 1998; Irvin et al., 2006).Weeds are also companion plants in orchards and may shelter natural enemies (Kozár et al., 1994), especially flower weeds (Leius, 1967; Zandstra and Motooka, 1978; Wyss, 1995) and nettle *Urtica dioica* (Stary, 1983; Hérard, 1986). The plant cover not only shelters an abundant arthropod community likely to offer alternate preys or hosts, but also orchard pests: aphids, mites (Meagher and Meyer, 1990a), phytophagous mirids (Fye, 1980), leafhoppers (McClure et al., 1982; Meagher and Meyer, 1990b), tortricids (Brown, 2001b) and Coleoptera (Wyss, 1996). However, the migration of these pests towards the cultivated trees is often more affected by the management of the plant cover than by the plant cover itself: weeding leads the hosted pests to migrate towards another resource, i.e. orchard trees (Van Emden and Williams, 1974;

McClure et al., 1982; Westigard et al., 1990; Flexner et al., 1991). Natural enemies hosted by the plant cover of the alleys are also negatively affected by frequent mechanical mowing (Horton et al., 2002).

For the total arthropod fauna and beneficial complex, the presence of a grassy ground cover within the orchard increases (Altieri and Schmidt, 1985) or not (Wyss, 1996) the diversity of beneficial arthropods. Responses in terms of pest control vary widely according to the pests (Altieri and Schmidt, 1985; Brown and Glenn, 1999), and most of the studied plant covers address one or a few key pests. Many studies in Northern America focus on the effect of understorey covers on mite populations in orchards. Information is provided on the conditions for optimal biological control of spider mites by predatory mites in terms of surface area to be covered by grass, distance to fruit trees, and composition of the plant assemblage (Nyrop et al., 1994; Croft, 1982; Alston, 1994). In pear orchards, both an increase in Anthocorid numbers and a decrease in *C. pyri* prey are assessed when a grassy ground cover is sown in the alleys compared with bare ground (Rieux et al., 1999). Flower strips in apple orchards enhance *D. plantaginea* control (Wyss et al., 1995; Pfammater and Vuignier, 1998). By providing a within-orchard higher density of preys they contribute to maintaining a high density of spiders and generalist predators, which prey on immigrating aphids in autumn, and can survive on, and control, low densities of preys. In spring, flower strips are also expected to favour aphidiphagous syrphids (Wyss, 1995), but this effect is not displayed in a second experiment (Vogt et al., 1998; Vogt and Weigel, 1999), most probably because of a delayed bloom in a Northern region and the mowing of the strips in winter. Lastly, very few studies (Irvin et al., 2006) address all the processes involved in the tri-trophic system targeted by plant manipulations: food preference of each orchard pest, effect of companion plants on the abundance and the fitness of the natural enemies to promote, predation or parasitism rates in the orchard and interactions with other natural enemies. The plant ground cover is therefore a plant component of the orchard which is easily manipulated and experimented on. A wide range of plant assemblages targeting various pests has already been tested with promising results. As for hedgerows, we notice that empirical, rather than scientific, knowledge is involved in most cases. Consequently, beyond adverse effects due to the management of the plant cover, failure or success cases in pest control cannot be explained and results are not always reproducible. Further research is needed to identify occurring processes and the ability of both pests and beneficial arthropod species to exploit both understorey and arboreal resources.

3.2. Effect of surrounding land uses

The association of both agricultural and uncultivated areas has been considered to preserve biodiversity (Grison and Billiotti, 1953) and to favour natural enemies of crop pests (Chaubet, 1993; Sarthou, 1995; Landis et al., 2000; Deguine and Ferron, 2004; Tscharntke et al., 2007). Integrated Fruit Protection (OILB, 1977) and ecological compensation areas (Garnier, 1994; Herzog et al., 2005) rely on such association in order to enhance natural control of orchard pests and to increase biodiversity, respectively. The effect of local or regional landscape on the arthropod populations of orchards is reported by many authors (Liss et al., 1986; Altieri and Schmidt, 1986; Whalon and Croft, 1986; Szentkiràlyi and Kozár, 1991; Kozár, 1992; Bengtsson et al., 2005; Miliczky and Horton, 2005). Winged arthropods represent 50% of the total number of the orchard entomofauna and are strongly related to local and regional backgrounds (Szentkiràlyi and Kozàr, 1991; Kozàr, 1992). However, very few studies address the relationships or correlation between the features of the agricultural area and beneficial effects or pest control in orchards. The total surface area covered by uncultivated lands (woods, fallow fields) within 100 m around pear orchards is significantly and positively correlated with the total and beneficial arthropod diversity of the orchard, and negatively correlated with *C. pyri* pest numbers, whereas the types of crops and their relative importance within the same area are not significantly correlated. Hedgerows lining the orchards increase the above-mentioned correlation between surface areas of uncultivated lands and the orchard beneficial complex diversity (Simon, 1999). These results are consistent with the study by Gut et al. (1988), establishing that the development of *C. pyri* is low in plant diversified environments. Such approaches are similar to those based on landscape ecology and developed in vineyards (Van Helden et al., 2006).

The presence of alternate host plants of pests in the orchard surroundings permits the provision of refuge areas for insecticide-susceptible alleles. This is likely to contribute to the management of resistance to insecticides and therefore to the sustainability of crop protection methods, provided that susceptible alleles have a selective advantage on resistant ones when insecticides are no longer applied. For the rosy apple aphid whose primary host is the apple tree, as well as the codling moth hosted by cultivated fruit trees only (apple, pear, nut and quince trees), refuge zones for strains susceptible to insecticides are mainly unmanaged or organic orchards (Boivin et al., 2005). More than plant diversity, it is the diversity of cultural practices which is expected to be beneficial. Lastly, it is clear that the study and the management scales outstrip the orchard scale, due to the potential moving distances of various groups of arthropods (Lewis, 1969).

3.3. Predation by insectivorous birds

The integration of insectivorous birds into pest control patterns is of benefit with higher yields and income (Jones et al., 2005a). Such integration can be performed by increasing the number of artificial nesting sites within the orchard, especially for cavity-nesting passerine birds which lack natural cavities (Bishop et al., 2000). Sanz (2001) showed that such management of artificial nesting sites favours the installation of Tit populations. As all species of Tits feed their brood with Lepidoptera caterpillars, they may significantly reduce fruit damage caused by codling moth larvae (Mols et al., 2005). As birds generally avoid parasitised preys, the biological control of pests due to birds seems to be complementary to that of other bio-control agents (Jones et al., 2005b).

4. CONCLUSION

Beyond a global increase in the richness of the agrosystem, an increase in predation or parasitism favoured by the conservation of habitats of beneficial organisms is assessed in many studies. There are generally only partial effects for pest control which is insufficient to reduce the use of pesticides except for some pests, e.g. mites and psyllids, that can be tolerated at high levels of populations without any damage on fruits or reduction in yield. Further research is needed to investigate all of the processes involved in conservation biological control on different interconnected scales and to identify: (i) the most relevant beneficial candidates or association of candidates to be promoted among predators and parasitoids, generalists and specialists; and (ii) the species composition, age, density and design of plant assemblages that would maximise beneficial effects and minimise detrimental ones when considering the global orchard community. The reduction in pesticide exposition of orchard communities is certainly a key point to maximise ecosystem services for pest control. We also promote the redesign of orchard systems to meet such a purpose of an 'agroecologic' orchard. We particularly propose to investigate: (i) the effect of a decrease in the genetic (one clone) and spatial (linear arrangements) monotony of current orchard designs; (ii) the emphasis of some favourable traits of current orchard designs, i.e. multi-strata design, plant diversified environment and soil litter development. Options such as the interplanting of missing strata (i.e. bush layer), mix cropping coupled with the supervised management of the whole orchard plant diversity, and the management of the soil organic status are candidate issues to favour functional diversity for pest control; and (iii) the manipulation of the architectural and microclimatic traits of the fruit tree through genetics and tree training, as a tool to modify the habitat of orchard pests and the foraging area of their natural enemies, and therefore their development. Lastly, the challenge mainly relies on integrating all these tools on different interconnected scales, from fruit tree leaf infrastructures to orchard and landscape scales, in order to maximise ecosystem services on each scale and to implement synergistic effects.

Acknowledgements: The authors wish to thank C. Bussi for his advice on an earlier draft of this manuscript. We thank Katie L. and David Bennett for improving the English of the manuscript.

REFERENCES

Agerberg J. (2007) Impact des pratiques agricoles et du paysage sur l'avifaune des vergers de pommiers du Sud-Est de la France, Mémoire INRA Avignon – AgroParisTec, 57 p. + annexes.

Alston D. (1994) Effect of apple orchard floor vegetation on density and dispersal of phytophagous and predaceous mites in Utah, Agr. Ecosyst. Environ. 50, 73–84.

Altieri M.A. (1995) Agroecology: the science of sustainable agriculture, Westview Process, Boulder, USA

Altieri M.A., Schmidt L.L. (1985) Cover crop manipulation in Northern California orchards and vineyards: effects on arthropods communities, Biol. Agric. Hortic. 3, 1–24.

Altieri M.A., Schmidt L.L. (1986) The dynamics of colonizing arthropod communities at the interface of abandoned, organic and commercial apple orchards and adjacent woodland habitats, Agr. Ecosyst. Environ. 16, 29–43.

Andow D.A. (1991) Polycultures and pest populations, Annu. Rev. Entomol. 36, 561–586.

Andreev R., Olszak R., Kutinkova H. (2006) Harmful and beneficial entomofauna in apple orchards grown under different management systems, Bull. IOBC/wprs 29, 13–19.

Aubertot J.N., Barbier J.M., Carpentier A., Gril J.J., Guichard L., Lucas P., Savary S., Savini I., Voltz M. (2005) Pesticides, agriculture et environnement, Réduire l'utilisation des pesticides et limiter leurs impacts environnementaux, Expertise scientifique collective, synthèse du rapport, INRA & Cemagref, France, 64 p.

Audemard H. (1992) Population dynamics in codling moth, in: Van der Geest L.P.S., Evenhuis H.H. (Eds.), Tortricid pests: their biology, natural enemies and control, Elsevier Science Publishers, Amsterdam, pp. 329–338.

Balázs K., Jenser G., Bujáki G. (1996) Eight years' experiences of IPM in Hungarian apple orchards, Bull. IOBC/wprs 19, 95–101.

Baldi I., Mohammed-Brahim B., Brochard P., Dartigues J.-F., Salamon R. (1998) Long-term effects of pesticides on health: review of current epidemiologic knowledge, Rev. Epidemiol. Sante 46, 134–142.

Barbosa P. (1999) Conservation Biological Control, Academic Press, San Diego, USA, 396 p.

Barthelet B. (1982) Étude faunistique d'une haie brise-vent composite, Mémoire de l'École Nationale des Ingénieurs des Travaux Horticoles, Angers, 101 p.

Baudry O., Bourgery C., Guyot G., Rieux R. (2000) Les haies composites réservoirs d'auxiliaires, Ctifl, Paris, 116 p.

Bengtsson J., Ahnström J., Weibull A.C. (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis, J. Appl. Ecol. 42, 261–269.

Benton T.G., Vickery J.A., Wilson J.D. (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18, 182–188.

Berrie A., Cross J. (2006) Development of an integrated pest and disease management system for apples to produce fruit free from pesticide residues - aspects of disease control, Bull. IOBC/wprs 29, 129–138.

Bishop C.A., Collins B., Mineau P., Burgess N.M., Read W.F., Risley C. (2000) Reproduction of cavity-nesting birds in pesticide-sprayed apple orchards in southern Ontario, Canada, 1988–1994, Environ. Toxicol. Chem. 19, 588–599.

Bogya S., Markó V. (1999) Effect of pest management systems on ground-dwelling spider assemblages in an apple orchard in Hungary, Agr. Ecosyst. Environ. 73, 7–18.

Bogya S., Markó V., Szinetár Cs. (1999) Comparison of pome fruit orchard inhabiting spider assemblages at different geographical scales, Agr. Forest Entomol. 1, 261–269.

Boivin T., Chadoeuf J., Bouvier J.-C., Beslay D., Sauphanor B. (2005) Modelling the interactions between phenology and insecticide resistance genes in the codling moth *Cydia pomonella*, Pest Manag. Sci. 61, 53–67.

Boller E.F., Häni F., Poehling H.M. (2004) Ecological infrastructures: ideabook on functional biodiversity at the farm level, Landwirtschaftliche Beratungszentrale Lindau, Lindau, Suisse.

Bouvier J.C. (2004) Exposition et réponse de l'avifaune aux pratiques phytosanitaires en vergers : Possibilités de traduction en termes de bioindication et de transfert vers la profession agricole, Mémoire d'Ingénieur Diplômé par l'État, spécialité Agriculture, ENSA Montpellier, 62 p. + annexes.

Bouvier J.C., Toubon J.F., Boivin T., Sauphanor B. (2005) Effects of apple orchard management strategies on the great tit (*Parus major*) in Southeastern France, Environ. Toxicol. Chem. 24, 2846–2852.

Brown M.W. (1993) Resilience of the natural arthropod community on apple to external disturbance, Ecol. Entomol. 18, 169–183.

Brown M.W. (1998) Diversification of orchard ecosystems to augment populations of biological control fauna, in: Brunnhofer V., Soldan T. (Eds.), Proc. 6th European Congress of Entomology (Book of Abstracts), Ceské Budejovice, August 23–29 1998, Institute of Entomology, Academy of the Czech republic and University of South Bohemia, pp. 623–624.

Brown M.W. (2001a) Functional biodiversity and agro-ecosystems management: 2. role in integrated fruit production, Bull. IOBC/wprs 24, 5–11.

Brown M.W. (2001b) Flowering ground cover plants for pest management in peach and apple orchards, Bull. IOBC/wprs 24, 379–382.

Brown M.W., Adler C.R.L. (1989) Community structure of phytophagous arthropods on apple, Environ. Entomol. 18, 600–607.

Brown M.W., Welker W.V. (1992) Development of the phytophagous arthropod community on apple as affected by orchard management, Environ. Entomol. 31, 485–492.

Brown M.W., Glenn D.M. (1999) Ground cover plants and selective insecticides as pest management tools in apple orchards, J. Econ. Entomol. 92, 899–905.

Brown M.W., Schmitt J.J. (2001) Seasonal and diurnal dynamics of beneficial insect populations in apple orchards under different management intensity, Biol. Control 30, 415–424.

Brown M.W., Schmitt J.J., Abraham B.J. (2003) Seasonal and diurnal dynamics of spiders (Araneae) in West Virginia orchards and the effect of orchard management on spider communities, Environ. Entomol. 32, 830–839.

Brown M.W., Mathews C.R., Krawczyk G. (2008) Analyzing the results of biodiversity experiments: enhancing parasitism of tufted apple budmoth, in: Proc. 7th IOBC International Conference on Integrated Fruit Production (Book of Abstracts), Avignon, October 28–30 2008, p. 6.

Bugg R.L., Waddington C. (1994) Using cover crops to manage arthropod pests of orchards: a review, Agr. Ecosyst. Environ. 50, 11–28.

Burgio G., Ferrari R., Boriani L., Pozzati M., van Lenteren J. (2006) The role of ecological infrastructures on Coccinellidae (Coleopera) and other predators in weedy field margins within northern Italy agroecosystems, Bull. Insect. 59, 59–67.

Campo L. (1992) La faune auxiliaire des haies composites : inventaire sur quatre sites du sud de la France, Mémoire de l'Institut Polytechnique, Toulouse, 64 p.

Carraretto L. (1992) Les haies composites : intérêt dans la protection intégrée, Mémoire d'ingénieur de l'École Supérieure d'Agriculture de Purpan, 89 p.

Chamberlain D.E., Fuller R.J., Bunce R.G.H., Duckworth J.C., Shrubb M. (2000) Patterns of change in the abundance of farmland birds in relation to the timing of recent intensification of agriculture in England and Wales, J. Appl. Ecol. 37, 771–788.

Chaubet B. (1993) Diversité écologique, aménagement des agroécosystèmes et favorisation des ennemis des cultures : cas des aphidiphages, Courr. Cell. Environ. INRA 18, 45–63.

Clergue B., Amiaud B., Pervanchon F., Lasserre-Joulin F., Plantureux S. (2005) Biodiversity: function and assessment in agricultural areas. A review, Agron. Sustain. Dev. 25, 1–15.

Codron J.M., Jacquet F., Habib R., Sauphanor B. (2003) Bilan et perspectives environnementales de la filière arboriculture fruitière, in: Quae (Ed.), Les Dossiers de l'Environnement de l'INRA 23: Agriculture, territoire, environnement dans les politiques européennes, pp. 31–67.

Coli W.M., Ciurlino R.A., Hosmer T. (1994) Effect of understory and border vegetation composition on phytophagous and predatory mites in Massachussetts commercial apple orchard, Agr. Ecosyst. Environ. 50, 49–60.

Commission Européenne (2008) http://ec.europa.eu/food/plant/protection/pesticides/legislation_fr.htm consulté le 10/03/2009.

Cortesero A.M., Stapel J.O., Lewis W.J. (2000) Understanding and manipulating plant attributes to enhance biological control, Biol. Control 17, 35–49.

Croft B.A. (1982) Management of apple orchard weeds to improve biological control of spider mites, Abstracts Meet, Weed Sci. Soc. Am. 257, 134.

Debras J.-F. (2001) Optimisation du choix des essences d'une haie composite pour lutter contre le psylle du poirier *Cacopsylla pyri* L., Mémoire d'Ingénieur Diplômé par l'État, ENSA Montpellier, 80 p. + annexes.

Debras J.-F. (2007) Rôles fonctionnels des haies dans la régulation des ravageurs : Le cas du psylle *Cacopsylla pyri* L. dans les vergers du sud-est de la France, Thèse de doctorat de l'Université d'Avignon, Sciences de la vie, 239 p.

Debras J.-F., Cousin M., Rieux R. (2002) Mesure de la ressemblance de la faune utile du poirier avec celle de 43 espèces végétales pour optimiser la composition de haies réservoirs d'auxiliaires, Fruits 57, 55–65.

Debras J.-F., Torre F., Rieux R., Kreiter S., Garcin M.S., Van Helden M., Buisson E., Dutoit T. (2006) Discrimination between agricultural management and the hedge effect in pear orchards (south-eastern France), Ann. Appl. Biol. 149, 347–355.

Debras J.-F., Dussaud A., Rieux R., Dutoit T. (2007) Recherche prospective sur le rôle "source" des haies en production fruitière intégrée. Le cas des perce-oreilles : *Forficula auricularia* L. et *Forficula pubescens* Gené, C.R. Acad. Sci. Fr. 330, 664–673.

Debras J.-F., Senoussi R., Rieux R., Buisson E., Dutoit T. (2008) Spatial distribution of an arthropod community in a pear orchard (southern France), Identification of a hedge effect, Agr. Ecosyst. Environ. 127, 166–176.

Defrance H., Marboutie G., Atger P. (1987) Expérimentation d'une haie brise-vent composite, PHM Rev. Hortic. 280, 25–29.

Deguine J.-P., Ferron P. (2004) Protection des cultures et développement durable, bilan et perspectives, Courrier Cell. Env. INRA 52, 57–65.

Delmas Y. (1995) Peuplements d'Arthropodes d'un verger de pêchers, des haies de bordure et de la strate herbacée de l'inter-rang, Mémoire de l'École Nationale des Ingénieurs des Travaux de l'Horticulture et du Paysage, Angers, 56 p.

Doles J.L., Zimmerman R.J., Moore J.C. (2001) Soil microarthropod community structure and dynamics in organic and conventionally managed apple orchards in Western Colorado, USA, Appl. Soil Ecol. 18, 83–96.

Epstein D.L., Zack R.S., Brunner J.F., Gut L., Brown J.J. (2000) Effects of broad-spectrum insecticides on epigeal arthropod biodiversity in Pacific Northwest apple orchards, Environ. Entomol. 29, 340–348.

Eurostat (2002) The use of plant protection products in the European Union, Data 1992–1999, Eurostat report 2002.

Fazekas J., Kadar F., Lovei G.L. (1992) Comparison of ground beetle assemblages (Coleoptera: Carabidae) of an abandoned apple orchard and the bordering forest, Acta Phytopathol. Entomol. Hung. 27, 233–238.

Finke D.L., Denno R.F. (2006) Spatial refuge from intraguild predation: implications for prey suppression and trophic cascades, Oecologia 149, 265–275.

Fitz Gerald J.D., Solomon M.G. (2004) Can flowering plants enhance numbers of beneficial arthropods in UK apple and pear orchards? Biocontrol Sci. Techn. 14, 291–300.

Flexner J.L., Westigard P.H., Gonzalves P., Hilton R. (1991) The effect of groundcover and herbicide treatment on twospotted spider mite density and dispersal in southern Oregon pear orchards, Entomol. Exp. Appl. 60, 111–123.

Fluetsch K.M., Sparling D.W. (1994) Avian nesting success and diversity in conventionally and organically Managed orchards, Environ. Toxicol. Chem. 13, 2118–2124.

Forman R.T.T., Baudry J. (1984) Hedgerows and hedgerow networks in Landscape Ecology, Environ. Manag. 8, 495–510.

Furness R.W., Greenwood J.J.D. (1993) Birds as monitors of environmental change, Chapman and Hall, London, 288 p.

Fye R.E. (1980) Weed sources of *Lygus* bugs in the Yakima valley and Columbia basin in Washington, J. Econ. Entomol. 73, 469–473.

Fye R.E. (1983) Cover crop manipulation for building pear psylla (Homoptera: Psyllidae) predator populations in pear orchards, J. Econ. Entomol. 76, 306–310.

Garnier M. (1994) Milieux naturels servant à la compensation écologique, Document environnement n°17, OFEFP, Berne, 35 p.

Gauthier J. (1993) Haies composites et strate herbacée : incidences sur les populations d'arthropodes d'un verger de pêchers conduit en protection intégrée dans la moyenne vallée du Rhône, Mémoire de l'École Nationale des Ingénieurs des Travaux de l'Horticulture et du Paysage, Angers, 58 p.

Genghini M., Gellini S., Gustin M. (2006) Organic and integrated agriculture: the effects on bird communities in orchard farms in northern Italy, Biodivers. Conserv. 15, 3077–3094.

Gingras D., Boivin G. (2002) Effect of plant structure, host density and foraging duration on host finding by *Trichogramma evanescens* (Hymenoptera: Trichogrammatidae), Environ. Entomol. 31, 1153–1157.

Greaves M.P., Marshall E.J.P. (1987) Field margins: definitions and statistics, in: Way J.M., Greig-Smith P.W. (Eds.), Field margins: definitions and statistics, British Crop Protection Council, Farnham, UK, pp. 3–10.

Green R.E., Osborne P.E., Sears E.J. (1994) The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland, J. Appl. Ecol. 31, 677–692.

Grison P., Biliotti E. (1953) La signification des "stations-refuges" pour la faune entomologique, C.R. Acad. agric. Fr. 39, 106–109.

Gruys P. (1982) Hits and misses. The ecological approach to pest control in orchards, Entomol. Exp. Appl. 31, 70–87.

Gut L.J., Westigard P.H., Liss W.J. (1988) Arthropod colonization and community development on young pear trees in Southern Oregon, Melandaria 46, 1–13.

Hall R.W., Ehler L.E. (1979) Rate of establishment of natural enemies in classical biological control, Bull. Entomol. Soc. Am. 25, 280–282.

Harwood R.W.J., Wratten S.D., Nowakoski M. (1992) The effect of managed fields margin on hoverfly (Diptera: Syrphidae) distribution and within fields abundance, in: Brighton Crop Protection Conference – Pests and Diseases. British Crop Protection Council, Hampshire, UK, pp. 1033–1037.

Hérard F. (1986) Annotated list of the entomophagous complex associated with pear psylla, *Psylla pyri* (L.) (Hom.: Psyllidae) in France, Agronomie 6, 1–34.

Herzog F., Dreier S., Hofer G., Marfurt C., Schupbach B., Spiess M., Walter T. (2005) Effect of ecological compensation areas on floristic and breeding bird diversity in Swiss agricultural landscapes, Agr. Ecosyst. Environ. 108, 189–204.

Hole D.G., Perkins A.J., Wilson J.D., Alexander I.H., Grice P.V., Evans A.D. (2005) Does organic farming benefit biodiversity? Biol. Conserv. 122, 113–130.

Horton D.R., Broers D.A., Lewis R.R., Granatstein D., Richard S.Z., Unruh T.R., Moldenke A.R., Brown J.J. (2002) Effects of mowing frequency on densities of natural enemies in three Pacific Northwest pear orchards, Entomol. Exp. Appl. 106, 135–145.

IDF Institut pour le Développement Forestier (1981) Réalisation pratique des haies brise-vent et bandes boisées, IDF, Paris, 129 p.

Irvin N.A., Scarratt S.L., Wratten S.D., Frampton C.M., Chapman R.B., Tylianakis J.M. (2006) The effects of floral understoreys on parasitism of leafrollers (Lepidoptera: Tortricidae) on apples in New Zealand, Agr. Forest Entomol. 8, 25–34.

Jeanneret P. (2000) Interchanges of a common pest guild between orchards and surrounding ecoystems: a multivariate analysis of landscape influence, in: Ekbom B., Irwin M.E., Robert Y. (Eds.), Interchanges of insects between agricultural and surrounding landscapes, Kluwer Academic, Dordrecht, Netherlands, pp. 85–107.

Jenser G., Balázs K., Erdélyi Cs., Haltrich A., Kádár F., Kozár F., Markó V., Rácz V., Samu F. (1999) Changes in arthropod population composition in IPM apple orchards under continental climatic conditions in Hungary, Agr. Ecosyst. Environ. 73, 141–154.

Jones G.A., Sieving K.E., Jacobson S.K. (2005a) Avian diversity and functional insectivory on North-Central Florida farmlands, Conserv. Biol. 19, 1234–1245.

Jones G.A., Sieving K.E., Jacobson S.K., Avery M.L., Meagher R.L. (2005b) Parasitized and non-parasitized prey selectivity by an insectivorous bird, Crop Prot. 24, 185–189.

Jonsen I.D., Fahrig L. (1997) Responses of generalist and specialist insect herbivores to landscape spatial structure, Landscape Ecol. 12, 185–197.

Kozár F. (1992) Organization of arthropod communities in agroecosystems, Acta Phytopathol. Entomol. Hung. 27, 365–373.

Kozár F., Brown M.W., Lightner G. (1994) Spatial distribution of homopteran pests and beneficial insects in an orchard and its connection with ecological plant protection, J. Appl. Entomol. 117, 519–529.

Krebs J.R., Wilson J.D., Bradbury R.B., Siriwardena G.M. (1999) The second silent spring? Nature 400, 611–612.

Labrie G., Prince C., Bergeron J.M. (2003) Abundance and developmental stability of *Pterostichus melanarius* (Coleoptera: Carabidae) in organic and integrated pest management orchards of Quebec, Canada, Environ. Entomol. 32, 123–132.

Lacas J.-G., Voltz M., Gouy V., Carluer N., Gril J.-J. (2005) Using grassed strips to limit pesticide transfer to surface water: a review, Agron. Sustain. Dev. 25, 253–266.

Landis D.A., Wratten S.D., Gurr G.M. (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture, Annu. Rev. Entomol. 45, 175–201.

Langellotto G.A., Denno R.F. (2004) Responses of invertebrate natural enemies to complex-structured habitats: a meta-analytical synthesis, Oecologia 139, 1–10.

Lawton J.H. (1983) Plant architecture and the diversity of phytophagous insects, Ann. Rev. Entomol. 28, 23–39.

Leius K. (1967) Influence of wild flowers on parasitism of tent caterpillar and codling moth, Can. Entomol. 99, 444–446.

Le Roux X., Barbault R., Baudry J., Burel F., Doussan I., Garnier E., Herzog F., Lavorel S., Lifran R., Roger-Estrade J., Sarthou J.-P., Trommetter M. (2008) Agriculture et biodiversité. Valoriser les synergies. Expertise scientifique collective, synthèse du rapport, INRA (France).

Lewis T. (1969) The diversity of the insect fauna in a hedgerow and neighbouring fields, J. Appl. Ecol. 6, 453–458.

Liss W.J., Gut L.J., Westigard P.H., Warren C.E. (1986) Perspectives on arthropod community structure, organization, and development in agricultural crops, Annu. Rev. Entomol. 31, 455–478.

Longcore T. (2003) Terrestrial arthropods as indicators of ecological restoration success in coastal sage scrub (California, USA), Restor. Ecol. 11, 397–409.

Lys J.A., Nentwig W. (1994) Improvement of the overwintering sites for Carabidae, Staphylinidae and Araneae by strip-management in a cereal field, Pedobiologia 38, 238–242.

Mathews C.R., Bottrell D.G., Brown M.W. (2004) Habitat manipulation of the apple orchard floor to increase ground-dwelling predators and predation of *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), Biol. Control 30, 265–273.

Maudsley M. J. (2000) A review of the ecology and conservation of hedgerow invertebrates in Britain, J. Environ. Manage. 60, 65–76.

McClure M.S., Andreadis T.G., Lacy G.H. (1982) Manipulating orchard ground cover to reduce invasion by leafhopper vectors of peach X-disease, J. Econ. Entomol. 75, 64–68.

Meagher R.L., Meyer J.R. (1990a) Influence of ground cover and herbicide treatments on *Tetranychus urticae* populations in peach orchards, Exp. Appl. Acarol. 9, 149–158.

Meagher R.L., Meyer J.R. (1990b) Effect of ground cover management on certain abiotic and biotic interactions in peach orchard ecosystems, Crop Prot. 9, 65–72.

Meyer J.R., Zehr E.I., Meagher R.L. Jr., Salvo S.K. (1992) Survival and growth of peach trees and pest populations in orchard plots managed with experimental ground covers, Agr. Ecosyst. Environ. 41, 353–363.

Miliczky E.R., Horton D.R. (2005) Densities of beneficial arthropods within pear and apple orchards affected by distance from adjacent native habitat and association of natural enemies with extra-orchard host plants, Biol. Control 33, 249–259.

Miliczky E.R., Calkins C.O., Horton D.R. (2000) Spider abundance and diversity in apple orchards under three insect pest management programmes in Washington State, USA, Agr. Forest Entomol. 2, 203–215.

Miñarro A., Dapena T. (2003) Effects of groundcover management on ground beetles (Coleoptera: Carabidae) in an apple orchard, Appl. Soil Ecol. 23, 111–117.

Moles R.T., Breen J. (1995) Long-term change within lowland farmland bird communities in relation to field boundary attributes, Biology Environment - Proc. R. Ir. Acad. 95, 203–215.

Mols C.M.M., van Noordwijk A.J., Visser M.E. (2005) Assessing the reduction of caterpillar numbers by great tits *Parus major* breeding in apple orchards, ARDEA 93, 259–269.

Monteiro L.B., Dor C., Franck P., Lavigne C., Sauphanor B. (2008) Pest management practices and environmental factors affect natural regulation of the codling moth, in: Proc. 7th IOBC International Conference on Integrated Fruit Production (Book of Abstracts), Avignon, October 28–30, 2008, p. 99.

Neumann U. (1993) How to achieve better results with the mating disruption technique, Bull. IOBC/wprs 16, 93–98.

Noss R.F. (1990) Indicators for monitoring biodiversity: a hierarchical approach, Conserv. Biol. 4, 355–364.

Nyrop J.P., Minns J.C., Herring C.P. (1994) Influence of ground cover on dynamics of *Amblyseius fallacis* Garman (Acarina: Phytoseiidae) in New York apple orchards, Agr. Ecosyst. Environ. 50, 61–72.

OILB Organisation Internationale de Lutte Biologique (1977) Vers la production agricole intégrée par la lutte intégrée, Bull. IOBC/wprs 4, 1–163.

Ormerod S.J., Watkinson A.R. (2000) Editors' Introduction: Birds and agriculture, J. Appl. Ecol. 37, 699–705.

Paoletti M.G., Boscolo P., Sommaggio D. (1998) Beneficial insects in fields surrounded by hedgerows in North Eastern Italy, Biol. Agric. Hortic. 15, 311–323.

Parfait G., Jarry M. (1987) Diversité végétale et impact des insectes phytophages : une revue bibliographique des méthodes appliquées au cas des cultures associées, Acta Oecol., Oecol. Gen. 8, 365–378.

Parish T., Lakhani K.H., Sparks T.H. (1994) Modelling the relationship between bird population variables and hedgerow and the other field margin attributes: species richness of winter, summer and breeding birds, J. Appl. Ecol. 31, 764–775.

Pearsall I.A., Walde S.J. (1995) A Comparison of Epigaeic Coleoptera Assemblages in Organic, Conventional, and Abandoned Orchards in Nova-Scotia, Canada, Can. Entomol. 127, 641–658.

Pekár S. (1999) Effect of IPM practices and conventional spraying on spider population dynamics in an apple orchard, Agr. Ecosyst. Environ. 73, 155–166.

Pekár S. (2003) Change in the community of epigeal spiders and harvestmen (Araneae, Opiliones) with the age of an apple orchard, Plant Soil Environ. 49, 81–88.

Pfammatter W., Vuignier R. (1998) Amélioration de la lutte biologique dans les cultures fruitières au moyen de bandes de plantes sauvages, in : 1er Colloque transnational sur les luttes biologique, intégrée et raisonnée, Lille, January 21–23, 1998, Région Nord-Pas-de-Calais, Lille, France, pp. 71–72.

PIRRP (2006) Plan Interministériel de Réduction des Risques liés aux Pesticides 2006-2009, Ministère de l'Environnement, de l'Énergie, du Développement durable et de l'Aménagement du territoire, http://www.ecologie.gouv.fr/Plan-interministeriel-de-reduction.html, consulté le 10/03/2009.

Pollard K.A., Holland J.M.(2006) Arthropods within the woody element of hedgerows and their distribution pattern, Agr. Forest Entomol. 8, 203–211.

Powell G.V.N. (1984) Reproduction of an atricial songbird, the redwinged blackbird, in field treated with organophosphate insecticide fenthion, J. Appl. Ecol. 21, 83–95.

Price P.W., Bouton C.E., Gross P., McPheron B.A., Thompson J.N., Weis A.E. (1980) Interactions among three trophic levels: influence of plants on interactions between insect herbivores and natural enemies, Ann. Rev. Ecol. Syst. 11, 41–65.

Prokopy R.J. (1994) Integration in orchard pest and habitat management, Agr. Ecosyst. Environ. 50, 1–10.

Prokopy R.J., Mason J.L., Christie M., Wright S.E. (1996) Arthropod pest and natural enemy abundance under second-level versus first-level integrated pest management practices in apple orchards: a 4-year study, Agr. Ecosyst. Environ. 57, 35–47.

Rands M.R.W. (1986) Effect of hedgerow characteristics on partridge breeding densities, J. Appl. Ecol. 23, 479–487.

Reboulet J.N. (1996) Bandes boisées ou enherbées : incidence sur les ravageurs et les auxiliaires des cultures voisines, Adalia 33, 22–24.

Reyes M., Franck P., Olivares J., Margaritopoulos J., Knight A., Sauphanor B. (2008) Worldwide variability of insecticide resistance mechanisms in the codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae), Bull. Entomol. Res., doi:10.1017/S0007485308006366.

Ricci B., Franck P., Toubon J.-F., Bouvier J.-C., Sauphanor B., Lavigne C. (2009) The influence of landscape on insect pest dynamics: a case study in southeastern France, Landscape Ecol. 24, 337–349.

Rieux R. (1994) Et si l'on pouvait aménager l'environnement végétal des cultures pour manipuler les auxiliaires ? Fruit Belge 447, 9–16.

Rieux R., Simon S., Defrance H. (1999) Role of hedgerows and ground cover management on arthropod populations in pear orchards, Agr. Ecosyst. Environ. 73, 129–140.

Risch S.J., Andow D., Altieri M.A. (1983) Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions, Environ. Entomol. 12, 625–629.

Robertson G.M., Eknert B., Ihse M. (1990) Habitat analysis from infrared aerial photographs and the conservation of birds in Swedish agricultural landscape, Am. Bio. 19, 195–203.

Rodet G. (1985) Incidence des zones refuge sur la dynamique de l'entomofaune d'un verger de pêchers, Mémoire de DEA, Université de Paris XI, Paris VI et Museum, 66 p.

Rosenzweig M.L. (1995) Species diversity in space and time, Cambridge University Press, Cambridge, UK.

Rösler S. (2003) Natur- und Sozialverträglichkeit des Integrierten Obstbaus, Ph.D. thesis University of Kassel, Germany, 430 p.

Russell E.P. (1989) Enemies hypothesis: a review of the effect of vegetational diversity on predatory insects and parasitoids, Environ. Entomol. 18, 590–599.

Sanz J.J. (2001) Experimentally increased insectivorous bird density results in a reduction of caterpillar density and leaf damage to Pyrenean oak, Ecol. Res. 16, 387–394.

Sarthou J.P. (1995) Haies composites et protection biologique : l'entomofaune associée aux essences ligneuses, in: Corroyer N., Garapon D., Arnal A. (Eds.), Mise en place et développement de haies composites en arboriculture biologique, Groupe de Recherche en Agriculture Biologique, Avignon, France, Annexe 2.

Sauphanor B. (2004) Réchauffement climatique et nuisibilité du carpocapse sur les pommiers, in: Lésel R. (Ed.), Effets du réchauffement climatique, Cahiers d'études et de recherches francophones / Agricultures 13.

Sauphanor B. (2009) Les phéromones d'insectes et la lutte par confusion sexuelle, in: Pintureau B., Grenier S., Mouret H., Sauge M.H., Sauphanor B., Sforza R., Tailliez P., Volkoff A.N. (Eds.), La lutte biologique, application aux arthropodes ravageurs et aux adventices, Ed. Ellipse, Coll. Technosup, Paris, pp. 52–73.

Sauphanor B., Audemard H. (1983) Analyse comparée des populations de Lépidoptères en en vergers de Pomacées par piégeage avec des phéromones de synthèse, Agronomie 3, 947–955.

Sauphanor B., Miniggio C., Faivre d'Arcier F. (1993) Effets à moyen terme des pesticides sur la faune auxiliaire en vergers de poiriers, J. Appl. Entomol. 116, 467–478.

Sauphanor B., Brosse V., Bouvier J.-C., Speich P., Micou A., Martinet C. (2000) Monitoring resistance to diflubenzuron and deltamethrin in French codling moth populations (*Cydia pomonella*), Pest. Manag. Sci. 56, 74–82.

Sauphanor B., Bouvier J.C., Boisneau C., Rieux R., Simon S., Capowiez Y., Toubon J.F. (2005) Impacts biologiques des systèmes de protection en vergers de pommiers, Phytoma Def. Veg. 581, 32–36.

Sauphanor B., Dirwimmer C. et al. (2009) Analyse comparative de différents systèmes en arboriculture fruitière, in: Ecophyto R&D : vers des systèmes de culture économes en produits phytosanitaires, Rapport d'Expertise Collective Inra, Inra Ed., Tome IV, 49 p.

Schoemans P. (1995) Intérêt des insectes et araignées présents sur des haies vis-à-vis de vergers de pommiers conduits en lutte intégrée, Fruit Belge 456, 117–123.

Shaltiel L., Coll M. (2004) Reduction of pear psylla damage by the predatory bug *Anthocoris nemoralis* (Heteroptera: Anthocoridae): the importance of orchard colonization time and neighbouring vegetation, Biocontrol Sci. Techn. 14, 811–821.

Simon S. (1999) Incidence de l'environnement végétal sur les populations d'arthropodes du verger de poiriers, Thèse de doctorat de l'Université de Montpellier 2, Biologie des populations et écologie, 438 p.

Simon S., Rieux R., Faivre d'Arcier F., Defrance H., Comte D. (1993) Aménagement de l'environnement végétal du verger de poiriers, in: ANPP Association Nationale de Protection des Plantes, 3^{e} Conférence Internationale sur les Ravageurs en Agriculture, Montpellier, December 7–9 1993, ANPP, Paris, pp. 1009–1016.

Simon S., Defrance H., Rieux R., Reboulet J.N. (1998) Les bandes boisées, réservoirs d'arthropodes : incidence sur la protection des cultures, Gibier Faune Sauvage, Game Wildl. 15(HS1), 33–42.

Simon S., Sauphanor B., Lauri P.-E. (2007a) Control of fruit tree pests through manipulation of tree architecture, Pest Techn. 1, 33–37.

Simon S., Defrance H., Sauphanor B. (2007b) Effect of codling moth management on orchard arthropods, Agr. Ecosyst. Environ. 122, 340–348.

Simon S., Sauphanor B., Defrance H., Lauri P.E. (2009) Manipulation des habitats du verger biologique et de son environnement pour le contrôle des bio-agresseurs. Des éléments pour la modulation des relations arbre-ravageur-auxiliaires, Innov. Agron. 4, 125–134.

Skirvin D.J. (2004) Virtual plant models of predatory mite movement in complex plant canopies, Ecol. Model. 171, 301–313.

Solomon G. (1981) Windbreaks as a source of orchard pests and predators, in: Thresh J.M. (Ed.), Pests, pathogens and vegetation: the role of weeds and wild plants in the ecology of crop pests and diseases, Pitman Books Ltd., London, pp. 273–283.

Solomon M.G., Cross J.V., Fitz Gerald J.D., Campbell C.A.M., Jolly R.L., Olszak R.W., Niemczyk E., Vogt H. (2000) Biocontrol of pests of apples and pears in northern and central Europe - 3. Predators, Biocontrol Sci. Techn. 10, 91–128.

Spellman B., Brown M.W., Mathews C.R. (2006) Effect of floral and extrafloral resources on predation of *Aphis spiraecola* by *Harmonia axyridis* on apple, BioControl 51, 715–724.

Stary P. (1983) The perennial stinging nettle (*Urtica dioica*) as a reservoir of aphid parasitoïds (Hymenoptera, Aphidiidae), Acta Entomol. Bohemoslov. 81, 81–86.

Stephens M.J., France C.M., Wratten S.D., Frampton C. (1998) Enhancing biological control of leafrollers (Lepidoptera: Tortricidae) by sowing buckwheat (*Fagopyrum esculentum*) in an orchard, Biocontrol Sci. Techn. 8, 547–558.

Suckling D.M., Walker J.T.S., Wearing C.H. (1999) Ecological impact of three pest management systems in New Zealand apple orchards, Agr. Ecosyst. Environ. 73, 129–140.

Szentkiràlyi F., Kozár F. (1991) How many species are there in apple insect communities?: testing the resource diversity and intermediate disturbance hypotheses, Ecol. Entomol. 16, 491–503.

Tasin M., Demaria D., Ryne C., Cesano A., Galliano A., Anfora G., Ioriatti C., Alma A. (2008) Effect of anti-hail nets on *Cydia pomonella* behavior in apple orchards, Entomol. Exp. Appl. 129, 32–36.

Tscharntke T., Bommarco R., Clough Y., Crist T.O., Kleijn D., Rand T.A., Tylianakis J.M., Van Nouhuys S., Vidal S. (2007) Conservation biological Control and enemy diversity on a landscape scale, Biol. Control 43, 294–309.

Tuovinen T. (1994) Influence of surrounding trees and bushes on the phytoseiid mite fauna on apple orchard trees in Finland, Agr. Ecosyst. Environ. 50, 39–47.

Van Emden H.F., Williams G.F. (1974) Insect stability and diversity in agro-ecosystems, Annu. Rev. Entomol. 19, 455–475.

Van Helden M., Fargeas E., Fronzes M., Maurice O., Thibaud M., Gil F., Pain G. (2006) The influence of local and landscape characteristics on insect pest population levels in viticulture, Bull. IOBC/wprs 29, 145–148.

Vogt H., Weigel A. (1999) Is it possible to enhance the biological control of aphids in an apple orchard with flowering strips? Bull. IOBC/wprs 22, 39–46.

Vogt H., Weigel A., Wyss E. (1998) Aspects of indirect plant protection strategies in orchards: are flowering strips an adequate measure to control apple aphids? in: Brunnhofer V., Soldan T. (Eds.), Proc. 6th European Congress of Entomology (Book of Abstracts), Ceské Budejovice, August 23–29, 1998, Institute of Entomology, Academy of the Czech republic and University of South Bohemia, pp. 625–626.

Westigard P.H., Flexner L.J., Vanburskirk P., Gonzalves P., Hilton R. (1990) Dispersal pattern of the twospotted spider mite from orchard groundcover into pear, Bull. IOBC/wprs 13, 53–57.

Whalon M.E., Croft B.A. (1986) Immigration and colonization of portable apple trees by arthropod pests and their natural enemies, Crop Prot. 5, 376–384.

Wildbolz T. (1988) Integrated pest management in Swiss apple orchards: stability and risks, Entomol. Exp. Appl. 49, 71–74.

Witzgall P., Stelinsky L., Gut L., Thomson D. (2008) Codling moth management and chemical ecology, Annu. Rev. Entomol. 53, 503–522.

Wyss E. (1995) The effects of weed strips on aphids and aphidophagous predators in an apple orchard, Entomol. Exp. Appl. 75, 43–49.

Wyss E. (1996) The effects of artificial weed strips on diversity and abundance of the arthropod fauna in a Swiss experimental apple orchard, Agr. Ecosyst. Environ. 60, 47–59.

Wyss E., Niggli U., Nentwig W. (1995) The impact of spiders on aphid populations in a strip-managed apple orchard, J. Appl. Entomol. 119, 473–478.

Yan Y., Yu Y., Du X., Zhao B. (1997) Conservation and augmentation of natural enemies in pest management of Chinese apple orchards, Agr. Ecosyst. Environ. 62, 253–260.

Zandstra B.H., Motooka P.S. (1978) Beneficial effects of weeds in pest management – a review, PANS 24, 333–338.

Zehnder G., Gurr G.M., Kühne S., Wade M.R., Wratten S.D., Wyss E. (2007) Arthropod pest management in organic crops, Ann. Rev. Entomol. 52, 57–80.

Zhang W., Ricketts T.H., Kremen C., Carney K., Swinton S.M. (2007) Ecosystem services and dis-services to agriculture, Ecol. Econ. 64, 253–260.