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# Farmers' management of functional biodiversity goes beyond pest management in organic European apple orchards

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ABSTRACT

Supporting functional biodiversity (FB), which provides natural pest regulation, is an environmentally sound and promising approach to reduce pesticide use in perennial cultures such as apple, especially in organic farming. However, little is known about farmers' practices and motivations to implement techniques that favor FB, especially whether or not they really expect anything from FB in terms of pest regulation. In fact, FB-supporting techniques (FB-techniques) are massively questioned by practitioners due to inadequate information about their effectiveness. An interview survey was performed in eight European countries(i) to describe farmers' practices and identify promising FB-techniques: (ii) to better understand their perceptions of and values associated with FB; and (iii) to identify potential drivers of (non-) adoption. Fifty-five advisors and 125 orchard managers with various degrees of experience and convictions about FB were interviewed and a total of 24 different FB-techniques which can be assigned to three different categories (ecological infrastructures, farming practices and redesign techniques) were described. Some were well-established measures (e.g., hedges and bird houses), while others were more marginal and more recent (e.g., animal introduction and compost). On average, farmers combined more than four techniques that had been implemented over a period of 13 years, especially during their establishment or conversion period. In general, it was difficult for farmers to evaluate the effectiveness of individual FB-techniques on pest regulation. They considered FB-techniques as a whole, targeting multiple species, and valued multiple ecosystem services in addition to pest regulation. The techniques implemented and their associated values differed among farmers who adopted various approaches towards FB. Three different approaches were defined: passive, active and integrated. Their appraisal of FB is even more complex because it may change with time and experience. These findings provide empirical evidence that the practical implementation of promising techniques remains a challenge, considering the diversity of situations and evaluation criteria. Increased cooperation between researchers, farmers and advisors should more effectively target research, advisory support and communication to meet farmers' needs and perceptions.

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## 1. Introduction

The intensification of agricultural production over the last decades has had broad detrimental effects, including biodiversity loss, landscape homogenization and environmental pollution (Geiger et al., 2010). In perennial crops such as apple, a high pesticide input is now required to decrease the level of injury from pests and diseases, even in organic farming where fewer and less persistent pesticides are authorized. At the same time, orchards provide the space and time to establish and maintain functional biodiversity (FB) that can provide regulatory services to control pests and diseases (Simon et al., 2010). Increasing attention is thus given to FB maintenance and support as a strategy to improve (fruit) production, especially within the framework of organic and agroecological systems whose principles and practices are based on environmentally -friendly practices (Drinkwater, 2009; Deguine and Penvern, 2014; Marliac et al., 2015).

Although it has been reported that the implementation of FB supporting techniques (FB-techniques) assumes a considerable investment by the farmer (Bianchi et al., 2013; Duru et al., 2015), little is known about what motivates farmer's adoption of such techniques and whether or not they expect a contribution from FB in terms of pest regulation. Yet, the farmer's motivation is a prerequisite for the implementation of biodiversity-based practices (de Snoo et al., 2013). Biodiversity and, fundamentally, functional biodiversity are associated with the concept of ecosystem services, i.e., ecological processes that is utilized to enjoy certain benefits (Fisher and Turner, 2008), that elicit economic perspectives (Lead et al., 2010; Howard et al., 2016). According to this framework, pest regulation is an ecosystem service with an economic value for farmers and practitioners may expect economic return if they invest in it, e.g., yield increases and reduced need for pesticide applications. Currently, the benefits of FB-techniques are still under debate among practitioners due to incomplete information about their contribution to pest control (Pannell et al., 2006; Brodt et al., 2009; Bianchi et al., 2013; Home et al., 2014; Howard et al., 2016), and little is known about their relative advantages compared to pesticide use. Reasons are multiple.

A first reason is the difficulty to assess the service of pest regulation. Various indicators have been proposed in the literature to evaluate the effectiveness of FB-techniques (Demestihas et al., 2017; Samnegård et al., 2019), but they are not yet consistent. Although they may present evidence for an increased abundance and diversity of beneficials, parameters such as predation rate are rarely assessed and the gaps between natural pest control, crop damage, crop yield and profitability remain (Letourneau and Bothwell, 2008; Cahenzli et al., 2019). In addition, these processes are highly site-specific, resulting in between-site variability, not only due to varying landscape and pedoclimatic contexts, but also varying farming strategies with unique combinations of FB-techniques and other farming practices (Marliac et al., 2015). Finally, knowledge about biodiversity impacts on ecosystem services is still limited to a few taxa and to the plot scale. Knowledge on the applicability of FB-techniques to multi-trophic and spatially heterogeneous agroecosystems is therefore insufficient (Bianchi et al., 2013).

Second, FB-techniques may provide other benefits beyond pest regulation. Many authors recognize the major current challenge and necessity to consider the ecological control of pests within a set of multiple services to be managed (Lescourret et al., 2015; Rapidel et al., 2015). Ground cover may be managed for the purpose of favoring predators and thus contributing to pest control, while at the same time reducing evapotranspiration and improving soil fertility by adding organic material to the soil. Studies on the adoption of FB-techniques also stress the importance of ethical and social biodiversity benefits, including esthetics, cultural contentment and recreation (Gurr et al., 2003; Fiedler et al., 2008; Brodt et al., 2009; Kelemen et al., 2013; Schmidt et al., 2016). For several farmers who participated in the Brodt et al. (2009) study, edge planting was associated with "*a mixture of sheer interest and esthetic enjoyment in seeing plants and associated vertebrate wildlife*" (page 202).

Third, stakeholders may have different perceptions of services because the way that benefits are valued is subjective (Lead et al., 2010; Smith and Sullivan, 2014). It should also be realized that many people benefit from ecosystem services without realizing it, and thus fail to appreciate their value (Lead et al., 2010). It may be concluded that FB-techniques development would be more effective if the various values of decision-makers were taken into account in the evaluation process (Kelemen et al., 2013; Hauck et al., 2016). In order to benefit from the farmer's knowledge of what works best on his or her individual farm: "*on-farm nature conservation interventions will be most effective if the farmers are convinced of their value and that they fit within the farmer's way of thinking*" (Home et al., 2014). However, socio-cultural issues are still poorly addressed in the dominant literature that assesses the effectiveness of FB-techniques (Burton et al., 2008; Brodt et al., 2009; Bianchi et al., 2013; Howard et al., 2016; Schmidt et al., 2016).

For all of these reasons, the information on FB-techniques is insufficiently adapted to farmers' management situations. To identify which parameters are important to farmers when managing FB-techniques should provide information about farmers' expectations and management constraints that may impede or foster the adoption of FB techniques. The literature on stakeholders' perceptions of biodiversity and on the drivers of biodiversity-based practices is quite abundant, especially within the scope of agri-environmental schemes to target, assess and adjust policy tools for biodiversity conservation. Nevertheless, fewer studies have addressed farmland biodiversity (Kelemen et al., 2013) and even fewer have focused on functional biodiversity (Bianchi et al., 2013). Stakeholder perceptions in FB thus remains an important challenge and there is a need for further research capable of assessing the willingness of farmers to apply FB-techniques and to account for the additional benefits they may provide (Brodt et al., 2009; Smith and Sullivan, 2014; Teixeira et al., 2018). This information may be useful, for example, when designing agroecosystems or extension materials.

Farmers and advisors involved in apple production in eight countries were interviewed for this study with the aim (i) to describe farmers' techniques to support FB, (ii) to better understand their perceptions and expectations towards FB, and (iii) to identify potential drivers of (non-)adoption. We first described the FB-techniques farmers implement in order to identify promising FB-techniques with the potential for a wider expansion. We then analyzed the benefits and disadvantages that farmers attributed to FB-techniques to define the criteria they use to evaluate FB-techniques. Lastly, we performed statistical analyses to identify potential adoption factors among variables describing farmers' profiles, farm contexts and FB-techniques.

## 2. Materials and methods

### 2.1. The sample interviewed

The sample was built by scientists in eight countries spread across a number of European pedoclimatic zones: Belgium, Denmark, France, Germany, Italy, Latvia, Sweden and Switzerland. The interviews were structured in two steps: first, with advisors (nA = 55) to (i) pre-define potential FB techniques, and (ii) identify farmers of interest to the study; and second, with selected farmers (nF = 125) identified primarily by the advisors (47%) and from other sources (personal acquaintances, project partners and other farmers). The farmer sample targeted orchard managers (not farm workers) who used organic farming practices with at least 50% of the orchard dedicated to apple trees. To describe as many drivers and limitations for the adoption of FB techniques as possible, the sample also included some farmers involved in Integrated Production (IP) (nF = 13, 11%), farmers with varying degrees of experience in fruit production and organic farming, and farmers with various degrees of "conviction" about FB, i.e., confidence in the effectiveness of FB techniques in terms of pest regulation (Home et al., 2014) (26% of the farmers said they were skeptical of FB). A total of 118 farmers were finally selected to ensure a minimum number of individuals for cross-country comparison and further statistical analysis.

### 2.2. The questionnaire

Common English-based questionnaires were designed and then translated by each European partner into their own language. Precise definitions of the vocabulary used were discussed among interviewers to guarantee a common understanding and to avoid translation confusion and approximation.

Both the advisor and farmer questionnaires were structured into four sections (supplementary material, SM1): (i) advisor and farmer features (e.g., type of advisory service and farming system); (ii) their perception of FB; (iii) the FB-techniques they knew, recommended or implemented; and (iv) their evaluation of the FB-techniques. The advisor questionnaire included only closed-ended questions with pre-listed FB-techniques suggested to advisors using a list of multiple choices, with the possibility to add unanticipated techniques used in their area or that they are used to recommend. The farmer questionnaire included closed-ended questions regarding the farming systems, while open-ended questions were included in the three following sections (SM1). This method made it possible to collect farmers' personal and spontaneous opinions without influencing and limiting them with pre-listed answers. The answers were then codified by the interviewer who quoted the farmers' own words. It should be mentioned that in some instances, farmers did not spontaneously mention all FB-techniques that we knew were implemented on their farms. They may have mentioned only the most recent or important FB-techniques that occurred to them at that moment. Other techniques that are too obvious (bird houses), not considered as a "technique" per se (e.g., existing hedges), or *a priori* not connected to FB (e.g., providing compost) but implemented in view of other benefits (e.g., hedgerows for windbreaks) may therefore not have been mentioned.

### 2.3. Data collection and analysis

Interviews were performed by each European partner in the stakeholders' native language, either by phone (for most advisors and nF = 71: 57%) or face-to-face (for some advisors and nF = 41: 33%) for a total of 55 advisor and 125 farmer interviews, unequally distributed among countries. Answers were then collected and organized in English through an online survey tool (LimeSurvey©). A common database was built and re-checked by all partners prior to a global and between-country analysis.

Data were translated into quantitative or qualitative variables and organized into three sets of variables (Table 1): (i) FB-techniques including the number and diversity of evaluation criteria farmers referred to; (ii) farmers' characteristics; and (iii) structural variables describing the production systems. As initially planned, the data collected covers a high diversity of systems and contexts across countries, such as degree of specialization, orchard area, advice frequency, average targeted yield and experience in fruit production and organic farming. For instance, the proportion of farms specialized in pome fruit production in the sample varied from 0% to 70% among countries.

First, an in-depth descriptive analysis was performed with correlation tests to identify category relationships, e.g., the number of benefits and disadvantages in relation to the number of FB-techniques implemented. Multivariate analysis was then performed with, on one side, the variables describing the farmer's experience with FB-techniques computed as active variables (section (i), Table 1) and, on the other, the

**Table 1**
Description and values of the variables built from the data collected with the farmers' interviews.

| FB techniques quantitative variables (i) | | Mean (Standard deviation) |
|---|---|---|
| FB_Ment | Number of FB techniques mentioned during farmer's interview | 5.3 (2.8) |
| FB_Impl | Number of FB techniques implemented on the farm | 4.3 (2.6) |
| FB_Inf | Number of ecological infrastructures implemented | 2.6 (1.9) |
| FB_Pra | Number of FB practices implemented | 1.1 (0.9) |
| FB_Red | Number of FB redesign techniques implemented | 0.3 (0.6) |
| FB_Exp | Number of years since first implementation of the FB technique (nF = 80) | 13.7 (10.7) |
| Benefits | Total number of benefits mentioned | 6.7 (3.8) |
| B_Crit | Number of criteria of benefits mentioned | 3.34 (1.47) |
| Dis-benefits | Total number of disadvantages mentioned | 1.9 (2.0) |
| DB_crit | Number of criteria of limits mentioned | 1.36 (1.27) |

| Farmer characteristic variables (ii) | | Sample mean (standard deviation or proportion) |
|---|---|---|
| Org_Exp | Number of years since organic conversion | 10.9 (SD = 10.3) |
| Apple_Exp | Number of years in apple production | 24.3 (SD = 18.2) |
| Training | The farmer said (s)he has been trained in FB | Yes (54%)/No (46%) |
| Oth_Occ | Other occupation outside the farm | Yes (43%)/No (57%) |
| Conviction | Degree of conviction about FB self-evaluated by the farmer | Skeptical (13%) // Convinced (77%) // NA: 10% |

| Production system structural variables (iii) | | Sample mean (standard deviation or proportion) |
|---|---|---|
| Apple_Surf | Surface area of apple orchard (ha) | 9.0 (SD = 10.6) |
| Pest_Ment | Number of pests mentioned | 2.8 (SD = 1.6) |
| Speci | Specialization degree of the farm | A (pome fruit production): 31% // B (pome and stone fruit): 15% // C (pome and small fruit): 13% // D (fruit and other crops): 22% // E (fruit and livestock husbandry): 19% |
| Targ_Yield | Yield targeted (tons/ha) | < = 10 tons/ha: 15% // [10; 20]: 19% // [20; 30]: 23% // [30; 40]: 6.8% // > = 40: 18% // NA: 19% |
| Marketing | Main marketing system (> 80%): short or long circuit | Short (29%) // Long (40%) // Both (31%) |
| Advisory | Number of advisors' visits in a year | None (26%) // < 3 (21%) / 3-6 (16%) // > 6 (17%) // OnD (On demand: 19%) |
| Cultivars | Type of apple cultivars | Standard (Yes = 62%, No = 38%) // Local (Yes = 57%, No = 43%) // Tolerant (Yes = 64%, No = 36%) |
| Planting | The farmer has new planting projects | Yes (69%) / No (29%) |
| Pest_First | Most harmul pest named | Codling Moth (35%)/Rosy Apple Aphid (14%)/Apple Sawfly (9.3%)/Other (31%) |
| Contact | Source of contact | Advisor (47%) // Personal (19%) // Project (9.3%) // Random (14%) // Other farmers (5.9%) |
| Country | Farmer's country | BE (5.9%) // CH (2.5%) // DK (12%) // DE (17%) // FR (24%) // IT (8.5%) // LV (17%) // SE (14%) |

**Table 2**
Description and occurrence of the 24 FB techniques identified with the 55 advisors and 118 farmers interviewed.

| | FB Techniques: brief description | Recommended by advisors (n = 55) | Farmers (n = 118) | | | |
|---|---|---|---|---|---|---|
| | | | Implemented | Knew | Abandoned | Total mentioned |
| Ecolgical Infrastructures | Bird houses and/or bat houses | 21 | 62 | 9 | 3 | 74 |
| | Hedgerows and forest strips: a row of shrubs or trees enclosing or seperating plots | 26 | 60 | 9 | 1 | 70 |
| | Flower strips: mix of flowering plants sown in strips or blocks | 14 | 47 | 17 | 5 | 69 |
| | Specific shelters for natural enemies | 16 | 27 | 17 | 3 | 47 |
| | Vertebrate shelters | 3 | 30 | 5 | 0 | 35 |
| | Raptor perches | 9 | 19 | 3 | 2 | 26 |
| | Wild bee houses | 0 | 16 | 1 | 1 | 18 |
| | Service plants: non-productive plant voluntarily introduced within the orchard | 2 | 9 | 2 | 0 | 11 |
| | Inter-row vegetal cover | 20 | 8 | 1 | 0 | 9 |
| | Fallowland and wasteland/Flowery meadow | 5 | 7 | 1 | 0 | 8 |
| | Body of water | 2 | 5 | 1 | 0 | 6 |
| Cultural Practices | Adapted inter-row management: alternate mowing, less frequent, grass rolling, etc. | 12 | 56 | 7 | 3 | 66 |
| | To create and maintain a diversified environment | 6 | 32 | 1 | 0 | 37 |
| | Pesticide use reduction | 27 | 27 | 1 | 0 | 29 |
| | Beneficial insect release | 8 | 9 | 4 | 0 | 13 |
| | Row management: mechanical weeding, tillage reduction or adaptation, etc. | 3 | 12 | 0 | 1 | 13 |
| | Tree robustness: through bottom-up approaches: fertilization limitation, irrigation and prunning adaptation, etc. | 4 | 7 | 0 | 1 | 8 |
| | Vertebrate release | 0 | 2 | 0 | 0 | 2 |
| | Prevention: mowing or shredding fallen leaves to prevent diseases; to keep ants away from apple trees; to facilitate aphid predation | 1 | 0 | 1 | 0 | 1 |
| System Redesign | Animal introduction into orchards (poultry, sheep, pigs, etc.) | 1 | 11 | 7 | 2 | 20 |
| | Crop diversification: association with cereals, vegetables, small fruits, etc. | 11 | 9 | 5 | 1 | 15 |
| | Fruit diversification: with tolerant apple cultivars, less vigorous rootstocks, and mixed pome and stone fruits | 5 | 11 | 1 | 1 | 12 |
| | Other practices: smaller plots, biodynamic, lower plantation density, no hail nets, etc., in opposition to standardized orchards and practices | 2 | 7 | 3 | 1 | 11 |
| | Pest monitoring | 3 | 2 | 0 | 0 | 2 |

variables describing the farmer's characteristics and his/her production system as illustrative variables (sections (ii) and (iii), Table 1). To draw up a farmer typology and identify discriminant factors, a multivariate analysis was performed using R software (R i386, version 3.2.3, R development Core Team 2012), package FactoMineR (Husson et al., 2016). These analyses included two steps: a principal component analysis (PCA) and a hierarchical cluster analysis (HCA). The main objective of the first method (PCA) was to reduce a large number of variables to a considerably more limited number of formal variables, referred to as principal components, with relatively little loss of information. This method allows to characterize the diversity of the sample and identify the most discriminant variables between individuals. The second method (HCA) was applied on the outcome of the PCA to identify clusters, i.e. relatively homogeneous groups of farmers, minimizing within-clusters and maximizing between-clusters dissimilarities. Complementary to this typology, a generalized linear model (Analysis of Covariance, ANCOVA) was used to identify potential influencing drivers for the adoption of FB-techniques.

## 3. Results

### 3.1. Farmers experience of FB techniques

A set of 24 techniques was defined (Table 2). Compared to the initial list defined by the interviewers and submitted to the advisors, the latter added indirect actions less commonly associated with FB such as practices to improve tree robustness (e.g., reduced mineral fertilization, adapted irrigation, pruning and thinning). Farmers generally spontaneously mentioned the FB-techniques selected by the advisors. Except for ‘wild bee houses’ and ‘vertebrate release’, farmers added a few variants, i.e., local adaptations of already listed techniques expressed by advisors, e.g., different management strategies of the ground cover (e.g., to roll grass instead of mowing), or systemic approaches such as “biodynamic farming”.

These 24 techniques can be grouped into three categories in order to distinguish long-term ecological infrastructures (e.g., inter-row vegetal cover); dynamic farming practices adaptable from one season to another (e.g., adapted inter-row management); and deeper system redesign techniques requiring strong interactions with the production system (e.g., crop diversification). On average, farmers combined 4.3 (+/- 2.6) FB-techniques on their farms. The most commonly implemented techniques belong to the first category, while deeper system redesign techniques were only mentioned by 10% of the farmers.

The four most commonly mentioned FB-techniques were ‘bird or bat houses’ (nF = 74), ‘hedgerows’ (nF = 70), ‘flower strips’ (nF = 69) and ‘adapted inter-row management’ (nF = 66). This includes FB-techniques that were implemented but later abandoned. This concerned only a few cases, meaning that FB adoption is generally long-lasting. Examples of abandonment were ‘flower strips’ (nF = 7% of the farmers who mentioned this FB-techniques), ‘insect shelters’ (nF = 6%) and ‘animal introduction’ (nF = 10%). For the sake of simplicity, we focused our analysis on implemented techniques.

There was a large variability between countries. Some FB-techniques are widely spread and common in all (’hedgerows and forest strips’ and ‘bird and bat houses’) or almost all (‘flower strips’ and ‘inter-row management’ in six out of eight countries, ‘pesticide use reduction’ and ‘a diversified environment’ in five) partner countries. On the contrary, some were specifically mentioned in one or a few countries: ‘inter-row vegetal cover’ in Latvia, ‘service plants’ in Sweden, ‘body of water’ in Italy, ‘crop diversification’ in Belgium and ‘other practices’ such as biodynamic farming, cultivation on smaller plots or lower plantation density, in France.

Farmers were also asked to specify the date of the first implementation for each technique, and they did so in 60.8% of the cases concerning 19 out of 24 techniques. According to these data, a FB-technique had been implemented for an average of 13.7 years but the variability was considerable ( ± 10.7 years). Fig. 1 illustrates this variability and distinguishes well-established techniques that were frequently implemented (e.g., “hedgerows’ and’ bird houses’) from others that were more recently adopted (e.g.,’ specific shelters’, ‘flower strips’ and ‘animal introduction’). Interesting figures appear when comparing implementation to farm history. In fact, some of the techniques were already in place on the farm before (up to 15 years) the current farmers were established, and 31% of the techniques were adopted during the set-up period (from 0 to 3 years after establishment). In parallel, 25% of the techniques were implemented before conversion to organic farming, and 45% during the conversion period (from 0 to 3 years). Correlation tests have also shown that a longer experience in organic farming (Pearson correlation test, ddl = 116, r = 0.25, $R^2$ = 0.06, P = 0.0006) and in apple production (r = 0.22, $R^2$ = 0.05, P = 0.015) were positively correlated with the number of FB-techniques implemented.

### 3.2. Farmers’ evaluation of FB techniques

Both farmers and advisors referred to multiple species targeted with the FB-techniques they implemented: either to enhance them (=” beneficial”) or to reduce the population (=” pest”). Species mentioned belonged to several taxonomic groups: arthropods, mammals (foxes, voles, bats, etc.), birds (raptor and insectivore), fungi (disease or soil biodiversity), trees and flowering plants from wild and domestic biodiversity (“*supporting beneficials by providing shelters with hedges and insect hotels, and nectar, especially for wild bees*”, DEF1 = the first farmer interviewed in Germany). One technique can focus on one specific species or group of species (e.g., bird houses, insect shelters) or be implemented to target multiple species or more general biodiversity

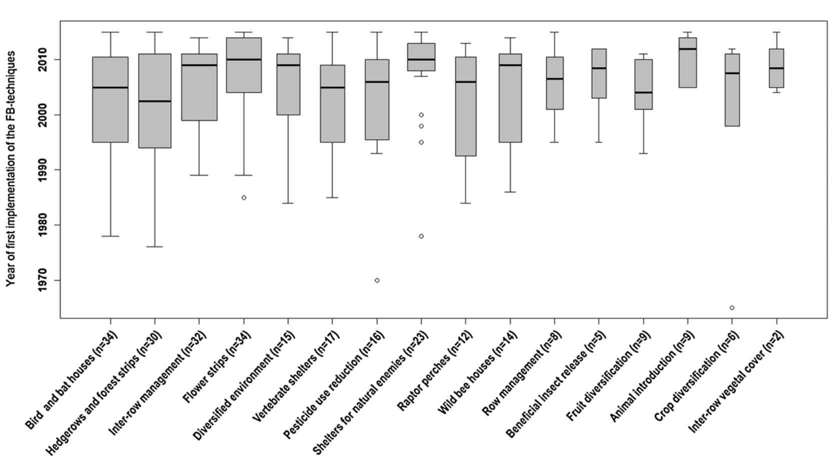


**Fig. 1.** Yearly distribution of the date of first implementation of the FB-techniques (n > 5) organized in decreasing order of implementation. This information has been recorded for only part of the techniques implemented by farmers (the number is specified in brackets). The width of the box plot is proportional to the occurrence for each technique.

often mentioned for hedges or alternate row mowing.

Farmers also expected multiple services from FB-techniques beyond pest regulation, such as apple production and quality, soil quality, pollination, tree nutrition, communication ("*because it attracts not only insects but also people and therefore provides a starting point for discussions about organic farming*", ITF5) and pleasant environment. Fig. 2 illustrates the diversity of associated services for two common FB-techniques. Farmers also emphasized the holistic dimension of FB, on the one hand ("*the best way to reach agroecological balance*", BEF4).

In order to identify promising techniques, farmers were asked to select the FB-techniques they found to be the "most efficient" and "easiest to implement". 'Flower strips', 'adapted inter-row management' and 'hedgerows' were among the several FB-techniques that farmers could rank and recognized as the most efficient and easiest to implement. However, 42.4% of the farmers did not answer the question, suggesting they have difficulties or express resistance to ranking FB-techniques. They were also asked to estimate the effect of each technique on pest regulation. All the techniques were assessed as being more positive than neutral or negative, especially 'bird and bat houses' and 'flower strips', which had the highest positive score. Nevertheless, here again, the proportion of "no answer" for each technique to be assessed was very high (74% on average). Farmers' comments on these questions provide an explanation. The criteria "technique efficiency" and 'easiness to implement' have different meanings for farmers. Some farmers observed an increase in beneficials, a reduction in pesticide use, and a reduction in pest population ("*big effect on* Adoxophyes orana", ITF1). However, most farmers admitted that they had difficulties measuring it ("*hedges represent a substantial investment for inconspicuous benefits*", FRF8; "*hard to evaluate and know what gives what*", SEF11). The effect on pest regulation was deduced ("a *long flowering season means that the insects remain on the farm*", DKF1), or hazardous rather than clearly observed. In addition, they considered FB-techniques as a whole and argued that assessment should consider not one specific FB-technique but their combination: "*hard to evaluate and know what gives what",* SEF11; "[I] d*on't think it is a single technique; it is the totality of things done",* SEF13.

Farmers were then asked to enumerate the other benefits and disadvantages of the FB-techniques they had implemented (see the list and occurrence of the benefits and disadvantages mentioned by the farmers for each FB-techniques in supplementary material 2). First, 36% of the farmers interviewed did not mention any disadvantages while 93% of the farmers mentioned some benefits and 66% at least two benefits. On average, farmers mentioned 6.65 (+/- 3.8) benefits and 1.93 (+/- 2.03) disadvantages for all techniques.

Crop protection was clearly the first criteria used by farmers both positively (recording 45% of all the benefits) and negatively (26% of all the disadvantages). Nonetheless, the analysis of benefits and disadvantages confirms that the farmer's evaluation clearly stretches beyond pest regulation and takes other considerations into account. The benefits and disadvantages were qualitatively analyzed and categorized into seven different criteria detailed in Table 3. On average, farmers mentioned benefits from 3.34 (+/- 1.47) different criteria and recognized the benefits of FB-techniques for crop protection and the environment (e.g., "*to save energy and increase soil fertility and find the best agroecological balance*", BEF5). They also mentioned disadvantages from 1.36 (+/- 1.27) different criteria, considering crop protection, economic and working conditions and technical disadvantages equally.

A comparison with advisors' answers highlighted the fact that they shared the same understanding, with few differences. Farmers enumerated a greater diversity of benefits for all criteria (e.g., energy saving, increased fruit quality or time saving mentioned as economic benefits). They were more concerned about working conditions, and enumerated a great diversity of technical disadvantages (Table 3),

Correlation tests showed that the more FB-techniques a farmer implemented, the more benefits (s)he mentioned (Pearson correlation test, ddf = 116, p-value = 2.2e-16, r = 0.80). The date of the first implementation of a FB-technique allowed us to define a variable describing the farmer's years of experience in FB-techniques in three modalities: "short" ≤ 5 y; "intermediate": 5 y to 20 y; and "long" ≥ 20 y. This analysis confirmed that more experienced farmers mentioned more benefits (ANOVA, ddf = 77, p-value = 0.00262, $R^2$ = 0.14), but not significantly more disadvantages (ANOVA, ddf = 77, p-value = 0.535, $R^2$ = 0.016).

However, the more widespread a FB-technique was, the more negative and diverse the feedback we collected was. In fact, the four most frequently mentioned FB-techniques accounted for the highest amount of benefits as well as of disadvantages. As illustrated by Fig. 3, the number of criteria used to assess benefits and disadvantages increased with the frequency of implementation.

### 3.3. Farmers' approaches to support functional biodiversity

A multivariate analysis was performed to highlight the relationships between variables describing farmers' experiences, their evaluations of FB-techniques (active variables) and the characteristics of their production system (illustrative variables) (Fig. 4).

PCA showed that all the active variables were positively correlated with the first dimension, explaining 47% of the inertia. It discriminated farmers who implemented many FB-techniques and mentioned multiple benefits (right) with farmers who implemented few FB-techniques and mentioned few benefits (left). Variables related to the number of disadvantages criteria built the second dimension (explaining 16% of the inertia). It discriminated farmers who mentioned few (at the top) and many (at the bottom) disadvantages both in number and in diversity. FB experience is linked to the third axis (not shown, 11% inertia).

The hierarchical classification allowed a deeper analysis and made

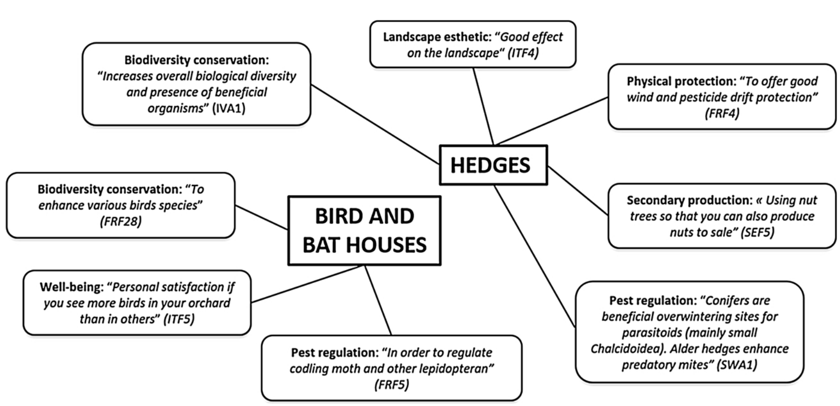


**Fig. 2.** Direct quotes extracted from the interviews to illustrate the multiple services farmers and advisors acknowledged for two FB-techniques they implemented: hedges and bird and bat houses. The codes following the verbatim quotes correspond to the country and succession number of farmer (F) or advisor (A) interviewed.

**Table 3**
Summary and frequency of the different benefits and disadvantages of the 24 FB-techniques the 118 farmers mentioned in the interviews. The benefits and disadvantages not mentioned by advisors are identified respectively in Bold and Italic.

| Criteria | Benefits | Total number of occurrence | Disadvantages | Total number of occurrence |
|---|---|---|---|---|
| Crop protection | Pest and disease regulation, attracts natural enemies (food/habitat), stronger trees. | 354 | Pest disease and/or weeds increase, voles and rodents increase. | 60 |
| Economy | Secondary production, **energy saving, fruit quality, time gain**. | 50 | Reduces production, *space-consuming*, high-cost, damage on apples, *shadowing*. | 50 |
| Environment | Overall biodiversity, landscape quality, water quality, reduces pollution, pollinator enhancement. | 158 | Animal introduction, reduces plant biodiversity. | 1 |
| Agronomy | Pesticide drift protection, wind protection, soil quality and microbiodiversity, water retention, soil-bearing capacity, **nitrogen supply, inter-row mowing limits competition**, holds moisture, **fertilization**, weed management. | 76 | Competition with apple trees. | 4 |
| Working conditions | Good smell, noise mitigation, esthetic, lower workload, life in the orchard, harmony, personal pleasure, personal philosophy. | 93 | *Time-consuming*, hard to apply and/or maintain, *risk of wasp nests*. | 57 |
| Technique | **Marks the boundary of the orchard**, locally adaptable, **interest for experimentation**, easy to implement, effective. | 17 | Incompatible with nets or other techniques, *low emergence rate, spraying restriction, shelters not occupied, parasitism, dangerous for machinery, only possible in small orchards, fox predation, requires major orchard adaptation, ineffective*, no differences with or without. | 48 |
| Social | Image, communication, marketing, **work diversification, patrimony**. | 37 | Mentality, *risk increase, poor visual effect, requires personal adaptation*. | 8 |

it possible to distinguish three groups (Fig. 4) that can be described according to significant differences among clusters:

- Cluster 1 (in black, Fig. 4) encompassed farmers who implemented few FB techniques (1.6 on average) and mentioned significantly less benefits and disadvantages (2.7 and 1, respectively), considering fewer criteria. Only economic and technical criteria did not significantly differ from the other groups, and most farmers said they were skeptical about FB. They generally had at least one activity outside of the farm and less apple surface area (5.4 vs. 8.9 on average for all the samples), less perceived problematic pests and a lower targeted yield. They did not plant either standard or resistant cultivars, and did not have new plantation projects. They were highly represented by the Latvian panel. This group may be referred to as the' **passive' approach** group since neither FB (nor measures for improving the yield) seem to be in focus in the production system.
- Cluster 2 (in red, Fig. 4) included farmers who implemented more FB-techniques (5.2 on average) with significantly more ecological infrastructures (3.2). They mentioned few disadvantages (1.4), considered relatively more environmental benefits and were generally convinced by FB. They said they were trained in FB and were highly represented by the German panel. FB is clearly a component of the production system, requiring specific actions underlying an **'active' approach** towards FB;
- Cluster 3 (in green, Fig. 4) was the smallest group, consisting of farmers with the highest number of FB techniques known and implemented (7.8 and 6.7 per farmer, respectively), significantly more "practices" and "redesign" FB-techniques (4.1 and 0.9, respectively). Most of them had an intermediary targeted yield. They mentioned significantly more benefits (11.2 on average, regardless of the technique) from all categories (an average of five criteria taken into account). They also mentioned the highest number of disadvantages (4.3 vs. 1.9 on average for all the samples) from all categories. They were highly represented by the French panel. Considering the number of FB-techniques and the diversity of evaluation criteria, this group distinguished itself from the others by its '**integrated' approach** to FB.

Complementary to this typology, an optimal linear model (ANCOVA, ddl = 104, $r^2$ = 0.54) including all the variables revealed that apart from the predominant effect of the country (p-value = $1.07.10^{-5}$), the training in FB (e.g., official training or personal interest; p-value = 0.00012), the use of resistant cultivars (p-value = 0.00052) and having new planting projects (p-value = 0.0051) are all positively correlated with the number of FB-techniques implemented. On the contrary, having other activities outside the farm is negatively correlated with the number of FB techniques implemented (p-value = 0.0276).

## 4. Discussion

The study's key point was to identify novel techniques for dissemination, to guide research effort towards most promising FB-techniques for uptake in the multipurpose context of the practical implementation and understanding of FB practices. Our findings emphasized different farmers' approaches towards FB according to the number and type of techniques they implemented, the number and diversity of criteria they mentioned to assess them and the characteristics of their production system. This analysis also suggest potential drivers for the adoption of FB-techniques.

### 4.1. Identifying innovative FB-techniques with the potential to be disseminated

The 24 FB-techniques we described emphasize the diversity of FB

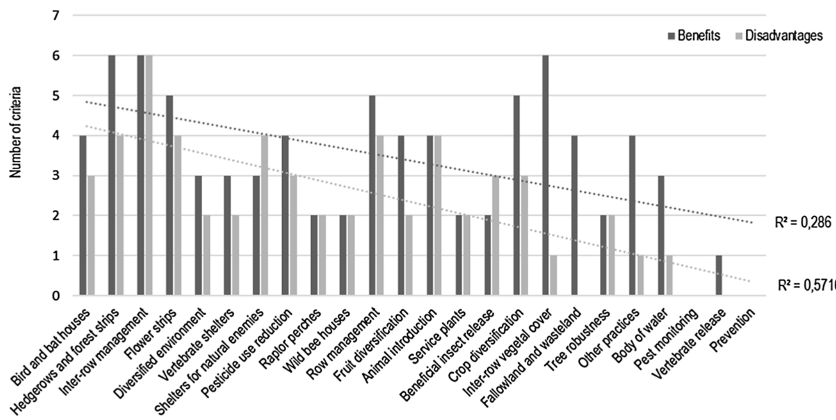


**Fig. 3.** Number of criteria used by the 118 farmers interviewed to evaluate the benefits (dark) and disadvantages (gray) of the 24 FB-techniques they implemented. Techniques are organized in decreasing order of implementation. Dotted lines indicate regression trend lines.

techniques already implemented by farmers, and allowed us to distinguish between techniques that were widely applied (e.g., hedges and bird houses) vs. techniques with the potential to be disseminated, i.e., more marginal and recent ones (e.g., animal introduction and compost). Our study thus contributes to the identification of little-known on-farm practices, i.e., to 'unearth alternatives to dominant practices", as expressed by Salembier et al. (2015), that are possibly promising and worth considering to target research and communication programs more in keeping with farmers' practices. In fact, most literature on FB focuses on ecological infrastructures and less attention has been given to farming practices. These dynamic practices have indirect resource-mediated effects and are therefore less commonly associated with FB. In addition, our study allowed us to define redesign techniques. They were often associated with a systemic approach and embraced a range of marginal practices such as a lower plantation density or intercropping with vegetables, in opposition to the dominant standard system, i.e., "*rethinking, abandoning monoculture*" (DEF15). The effect of these techniques on FB has not been well documented in the literature (Simon et al., 2010). They are yet increasingly recognized as a way to design innovative agroecosystems based on enhanced ecological processes (Malezieux, 2012; Ratnadass et al., 2012). Obtaining more insights into the factors underlying the application of innovative techniques, as we did via the collection of advisor and farmer feedback, should thus help farmers and advisors to transform these techniques into practices, i.e., to adapt them to the context of their farms (Casagrande et al., 2017).

In a methodological perspective, the completeness of the 24 techniques can yet be discussed as regard to the diversity of situations and quality of the interviews we reached. Sampling multiple European countries proved to be helpful to identify FB-techniques that are more specific to some countries with the potential of extending them to other countries (e.g., water ponds identified in Italy or service plants in Sweden).

According to our findings the diversity of FB-techniques identified is yet independent of the number of farmers interviewed and depends instead on farmers' FB-approaches. Farmers having an "integrated" FB-approaches appear as key targets to perform such inventory. They combined up to 12 FB-techniques with relatively more farming practices and redesign techniques and their experience and critical opinion of FB-techniques also shed light on many benefits as well as disadvantages. On the other hand, interviewing less experienced and less convinced farmers emphasizes the diversity of FB approaches and farming contexts. However, the diversity of situations we reached may be skewed by the snowball sampling method and the influenced of the interviewers' professional networks. Despite our effort to interview advisors and farmers with different degrees of conviction towards FB, a large majority of our sample (74%) was favorable to FB. It is probably easier for researchers working on biological control to reach interested (and convinced) farmers rather than skeptical ones. Moreover, focusing

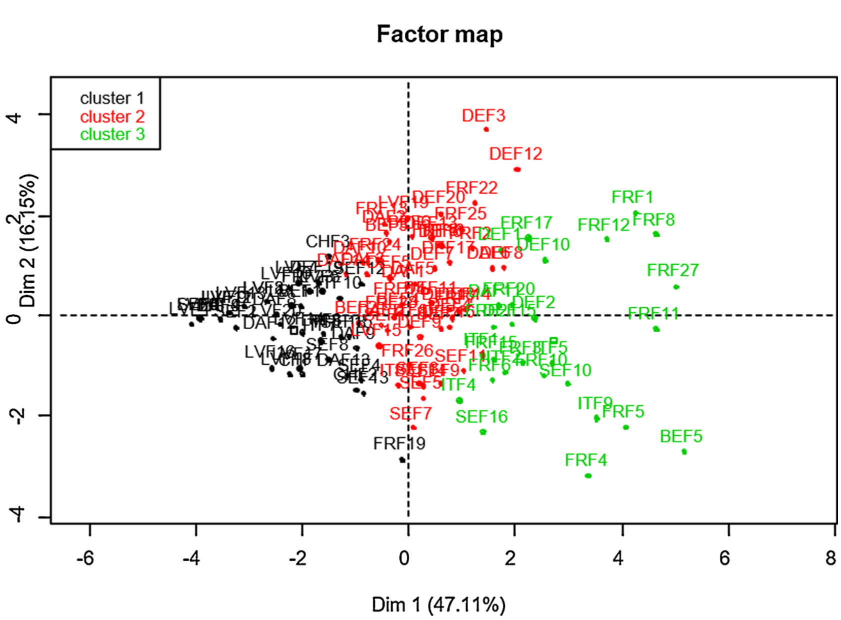


**Fig. 4.** Projection of the three groups of farmers' FB-approaches defined by the hierarchical classification and represented in colors on the first and second axis of the PCA. The variables contributing the most to the first axis were the number of FB-techniques implemented and the number of benefits mentioned. The second axis was mainly explained by the number of disadvantages mentioned. Each point represents a farmer interviewed.

on organic production may have restricted the diversity of FB-approaches that could be identified since organic farmers proved to have a relatively homogeneous and positive perception of biodiversity compared to conventional ones (Kelemen et al., 2013). Organic farmers often lack options for pest management, making them more interested in alternative pest management methods and biodiversity-based strategies (Penvern et al., 2010).

Moreover, very common techniques implemented by farmers may not have been mentioned spontaneously because they are too common, taken for granted, or not usually associated with FB. For example, reducing pesticide use is very common in organic farming (Marliac et al., 2015) but not systematically mentioned by organic farmers. Likewise, most farmers in Denmark and Sweden install bee houses to ensure pollination and bird houses for pest control, but both techniques were rarely mentioned by farmers in these countries, most likely because they were taken for granted. A pre-defined list of FB techniques could have been submitted to farmers, as it was done for advisors, but an open question was preferred in order not to influence the answer and collect unexpected techniques. Farmers in fact mentioned additional marginal and systemic techniques such as crop diversification or pest monitoring. Our categorization into a limited number of "techniques" can actually be restrictive since it fails to convey the many local variants mentioned by farmers or marginal techniques grouped into techniques such as in "other practices". It also excludes ways of thinking mentioned by farmers (e.g. to "*manage the orchard under a "living-way" rather than a killing-way*", BEF7) that are difficult to translate into operational techniques. Finally, a categorization cannot practically include detailed elements of an FB-techniques which may still be determining for its success on farms and resulting uptake by farmers, such as the plant composition of flower strips, where they are placed, and how they are successfully sown and managed (Pfiffner et al., 2019).

### 4.2. Selecting promising FB-techniques when farmers have a multi-value approach to FB

To estimate how promising the FB techniques were, farmers were first asked to select which techniques are the most efficient and the easiest to implement and, second, to qualify the effect of each technique on pest regulation. The number of respondents who did not answer suggests the difficulty for farmers to evaluate the costs and benefits of FB-techniques. Our findings confirm our first assumptions: (i) they target multiple species and not only pest regulation; (ii) they consider not one technique separately but the combination of techniques they implement; and (iii) they express a plurality of criteria that motivates their techniques adoption (on average, more than three) including non-utilitarian, environmental and social values. These findings suggest that farmers instead have an integrated approach to functional biodiversity management, already observed in most studies that investigated public understanding of the concept of biodiversity (Kelemen et al., 2013; Cerda and Bidegain, 2018) and which concluded with the need for a plural value approach in biodiversity valuation methods. No promising FB-techniques per se, i.e., combining all advantages farmers may expect, could and should thus be defined. Instead, the set of criteria we collected from farmers for each FB-technique (SM2) represents a practical tool for researchers and advisors to assist growers in their decision-making process. In addition, we observed that the more experienced farmers were, the more benefits they mentioned. This may be either a result of pre-existing conviction, i.e., experienced farmers were already convinced, or an evolution over time. For the latter, some assumptions to be explored in further studies can be made: (i) time may be needed to establish processes in the system and to observe the benefits and challenges of FB-techniques (Bostanian et al., 2004; Blaauw and Isaacs, 2012; Sigsgaard, 2014); (ii) time may be needed for farmers to gain experience and to adapt the FB-techniques to their conditions, possibly leading to increased benefits or reduced disadvantages (Pannell et al., 2006); (iii) farmers who have implemented FB-techniques for a long time may become more convinced of their benefits (Michel-Guillou and Moser, 2006). People may in fact be inclined to overestimate the costs associated with changes and underestimate their profits. As advocated by Pannell et al. (2006), offering readily testable techniques (easy-to-test and that can be learned about before adoption) may facilitate the adoption of FB-techniques. This is an even greater issue for perennial cropping systems where flexibility in testing and changing crop designs is hampered. This suggestion leads to an interest for self-monitoring methods to assess FB (Burton et al., 2008; Targetti et al., 2016) with relevant indicators (or biodiversity-related parameters) adapted to farmers and farming conditions to further enhance the ability of growers to evaluate these practices on their own, to evaluate impacts and adjust practices. However, it is still a challenge to monitor systemic and long-term processes and to interpret results, especially for ecologically-based practices. Farmers may see trends over time or compare their observations to other orchards, but the number of confounding factors is considerable.

Globally, results lead to a common recommendation is to increase cooperation between researchers, farmers and advisors to target research, advisory support and communication that is more consistent with farmers' needs.

Considering that farmers have different approaches towards FB suggests that research should continue to focus on different techniques and not only farming practices or ecological infrastructures. Attention should also be given to redesign techniques and explore the other benefits they may provide. Historically, FB-technique assessments were commonly performed by entomologists or agronomists who focused on pest regulation through a mono-disciplinary approach, missing possible synergies and competing benefits that may foster or limit adoption by farmers (Bianchi et al., 2013). On the contrary, such multi-value approach requires an understanding of the numerous relationships among management techniques and among biodiversity components and their functions, all of which makes any efficacy assessment difficult. Our findings also point to the need to advise farmers to take their expectations and knowledge about FB into account. Whole-farm advisory support has already been tested and was shown to effectively increase the uptake of biodiversity-friendly options (Chevillat et al., 2017). Advisors and farmers learning together not only how to monitor FB, but to understand the underlying mechanisms as well, is the key to helping those advisors and farmers to communicate and facilitate a wider adoption of FB-techniques. Some of the French farmers who had an integrated approach had participated in a group consisting of fruit growers, advisors and agricultural scientists (Penvern et al., 2012) with the aim to combine the diversity of skills and knowledge required to (re)design sustainable orchards. Their participation in this group is not a coincidence. Nevertheless, the analysis of the knowledge exchanged, for instance, on the "bad experiences not to be reproduced" (in reference to the numerous disadvantages they may share) in these types of participatory groups could be explored in order to analyze how it may or may not facilitate the adoption of FB-techniques (Berthet et al., 2016).

### 4.3. Drivers to foster the adoption of FB-techniques

The observed differences among countries stress the predominant role of the context for the adoption of FB-techniques. Many factors may explain between-country variability, such as the ecological contexts and pest pressure, in particular. In answer to the question, "*What are the five most harmful pests?*", apple growers in almost all of the countries emphasized the major role of the codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) and the rosy apple aphid *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae). However, other pests were also mentioned and were relatively country-specific, such as *Hoplocampa testidunea* Klug (Hymenoptera: Tenthredinidae) in Denmark, leafrollers in Sweden, and other secondary pests in Latvia. The variability observed may also be explained by other external socio-technical factors:

(i) previously existing infrastructures; (ii) cultural and traditional heritage (e.g., in Latvia, most orchards contain piles of stones collected from tilled land); (iii) different national and regional regulations (e.g., the availability of registered plant protection products based on microbials or the implementation of agri-environmental schemes with subsidies for some practices); (iv) communication about one technique in particular (e.g., in Denmark with recent studies on landscape and its effect on agriculture and biodiversity; in Sweden with ongoing participatory research projects on habitat manipulation and flower strips since 2011); and (v) the bias resulting from the different interview conditions (interviewers, face-to-face or by phone, farmers interviewed).

Apart from the country effect, the multivariate analysis allowed us to describe groups of farms with varying levels of adoption of FB-techniques. Farmers with a passive approach implemented less than two FB-techniques on average. This group concerned mostly pluri-active farmers, i.e., those who had other activities outside of the farm, without planting projects. They said they had little training in FB and a large majority of them said they were skeptical towards FB. Corroborated by further statistical analysis, our results suggest that training, planting projects and full-time on-farm activity are important prerequisites for the implementation of FB techniques. Dupré et al. (2017) performed an analysis among 31 farmers who cultivated citrus trees and found that the importance of crop production in farm revenue determined farmers' choices regarding crop production practices. In their case, however, farmers who did not expect high revenues from a given crop were ready to take more risks and adopt alternatives to synthetic inputs. In our case, pluri-active farmers used less FB-techniques, which may be explained by less (perceived) pest problems and available time. Latvian orchards are in fact very extensive with less pest and disease issues compared to more intensive production areas. Pluri-active Latvian farmers also often fail to notice pests like the apple blossom weevil (*Anthonomus pomorum* L.) or spider mites (*Panonychus ulmi* (Koch)) since their damage is not readily visible, e.g., blemished apples in the yield. On the contrary, farmers with an integrated approach who implemented more FB-techniques did not have other occupations outside of the farm and mentioned more harmful pests (3.3 on average compared to 2.0 for passive ones). They were not necessarily the most intensive, i.e., they had an intermediate apple surface area and yield target. This would suggest that "intermediate farms" are more likely to adopt FB-techniques. Of course, ideological conviction has not been investigated in this study but may play an important role in explaining why convinced farmers implement more FB techniques and mention more benefits.

Considering the type of FB-techniques, practices and especially redesign strategies were marginally implemented compared to ecological infrastructures. Referring to Hill's three stages evolving ecosystem approaches to fruit insect pest management (Michel-Guillou and Moser, 2006; Pannell et al., 2006; Home et al., 2014; Dupré et al., 2017), redesign strategies may entail deep system changes only achievable when planting new orchards. Perennial crops present special challenges and options linked to their spatial design, which limits changes in plant material and orchard structure. Nevertheless, our results indicate that orchard establishment, conversion period to organic farming and planting projects were related to the implementation of FB techniques. As emphasized by Dupré et al. (2017) for fruit tree production in Reunion Island (France) and by many other authors (Duru et al., 2015), the agroecological transition may be an incremental process. Our results suggest that the adoption and, even more, the evaluation of FB-techniques is a collective and long-lasting process.

## 5. Conclusions

The interviews conducted in eight different European countries among a diversity of organic apple farming systems allowed us to describe a broad spectrum of farmers' approaches towards functional biodiversity. This study contributes to the identification of little-known on-farm practices that are possibly promising and worth considering in order to target research and communication programs. Nevertheless, no promising FB techniques could be defined. The techniques they implemented and the criteria they use to assess them differed among farmers and may not (only) concern pest regulation. Farmers instead considered FB techniques as a whole, using a plurality of criteria including non-utilitarian, environmental and social values. The evaluation of FB-techniques is all the more complex in that it may change with the year of implementation. Our results also indicate that the management of FB techniques is a lasting and incremental process where farmers' establishment and conversion periods are favorable windows of opportunity. Training and full-time on-farm activity may be additional important prerequisites for the implementation of FB techniques. These findings finally highlight the opportunity to design research and extension programs more in agreement with farmers' situations, experience and values.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.05.014.

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