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Review

Opportunities and limitations for functional agrobiodiversity in the European context

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ABSTRACT

To counteract the negative effects of intensive agriculture there is increasing interest in approaches that reconcile agricultural production with the conservation and sustainable use of biodiversity and associated ecosystem services. Integration of functional agrobiodiversity (FAB) in agricultural systems holds promise to meet these challenging objectives, but requires the generation, transfer and implementation of tailor-made knowledge, and policy development. Currently various initiatives are undertaken across Europe to develop and assess the potential of biodiversity-based management practices by farmers, industry, researchers and governmental and non-governmental organizations. In this paper we show that the Convention on Biological Diversity and planned reforms in EU policy offer scope to further implement FAB concepts via legislation for biodiversity conservation, pesticide use, water quality, environmental protection and conservation of genetic resources. At the same time we observe that there are still impediments to the adoption of FAB approaches, including (i) translation of general knowledge to tailored, ready-to-use management practices, (ii) limited information on the effectiveness of FAB measures in terms of crop yield and quality, profitability, and reduction of agrochemical inputs, (iii) lack of appropriate financial accounting systems that allow fair accounting of the private investments and public benefits, and (iv) the implementation of FAB measures at the right spatial scales, which requires coordination among the various actors in a region. Current and new legislation may provide incentives to address these limitations and contribute to the further development and integration of FAB concepts in agricultural systems in Europe.

1. Introduction

While the intensification of agriculture has enabled substantial increases in European food production during the last 50 years, it has also transformed European landscapes and as such it is considered a major driver of the decline of farmland biodiversity (Donald et al., 2001; Green et al., 2005). Practices such as pesticide and synthetic fertilizer application, the large-scale use of a few high-yielding crop varieties, continued mechanization of agriculture through the use of heavy machinery and removal of (semi-)natural habitats have

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resulted in the simplification of agro-ecosystems at various spatial scales (Benton et al., 2003; Hendrickx et al., 2007). Current European trends are mixed: on the one hand there is increasing intensification and up-scaling in prime agricultural areas, particularly in Eastern Europe, on the other hand there is concern about land abandonment in areas that are considered marginal for agriculture. Both trends can have a negative impact on farmland biodiversity (e.g. Baldock et al., 1996; Verhulst et al., 2004).

There is growing concern that declines in biodiversity affect the delivery of ecosystem services, including those that are essential for agricultural production (Millennium Ecosystem Assessment, 2005). Indeed, pollinators that are vital for the production of many fruits and vegetables show a declining trend in The Netherlands and the UK (Biesmeijer et al., 2006), biological pest control services provided by predators and parasitoids tend to be lower in landscapes that are dominated by crops and have little non-crop habitats (Tscharntke et al., 2005), and soil management associated with intensive conventional agriculture can jeopardize ecosystem services regulated by soil biota, such as nutrient retention and water infiltration (Brussaard et al., 2007) and organic matter cycling (Jongmans et al., 2003).

To counteract the negative effects of intensive agriculture, there is increasing interest in approaches that reconcile agricultural production with the conservation and sustainable use of biodiversity and associated ecosystem services (Scherr and McNeely, 2008; Brussaard et al., 2010). A central concept in this regard is functional agrobiodiversity (FAB), i.e. biodiversity at the scale of agricultural fields or landscapes, which provides ecosystem services that support sustainable agricultural production and can also have a positive spin-off to the regional and global environment and society as a whole (ELN-FAB, 2010). It must be stressed that FAB and biodiversity conservation have different objectives and therefore require different approaches (Kleijn et al., 2011). FAB specifically focuses on organisms and landscape elements that are instrumental in supporting ecosystem services which are relevant for agricultural production, farmer's income, landscape and environment, whereas conservation efforts aim to safeguard the intrinsic value of biodiversity, and typically focus on rare or endangered species. Although synergies between FAB and biodiversity conservation are possible, this will not always be achieved (MacFadyen et al., 2012). The integration of FAB in agro-ecosystems requires understanding of those biodiversity elements that support ecosystem services, and translation of such knowledge into tailored farm and landscape management practices. Such management practices may entail conservation tillage, crop diversification or rotation, as well as informed choices on the integration of non-crop vegetation, such as field margins, hedgerows and woodlots in agricultural landscapes.

Besides the generation of tailor-made knowledge, the development and adoption of FAB measures requires knowledge transfer, implementation of knowledge and policy development, including the design of subsidy programmes (CREM, 2008). As a consequence, involvement from various scientific disciplines and close collaboration between a range of stakeholder groups (e.g. farmers, other land and water managers, private companies, research organizations, nature conservation organizations and governments) is required. In Europe several FAB initiatives have been taken bottom-up, through multi-stakeholder collaboration. To assess which FAB measures are generally applicable and effective, and which are context-specific, sharing of knowledge and experiences between programmes is essential. Yet, information on these initiatives and the associated practical experience is extremely fragmented and barely accessible. With the development of reforms in EU legislation new opportunities arise for the scaling-up of such FAB initiatives, emphasizing the need to evaluate the effectiveness and opportunities of FAB in a European context.

Historically, environmental policies in the EU have primarily focused on negative impacts of agriculture on biodiversity and ways to alleviate these. More recently, European farmers and policymakers have increasingly recognized that agricultural production and biodiversity need not necessarily be in conflict, but are interdependent and can strengthen each other. Here, we review a selection of FAB initiatives in Europe, and identify future perspectives. More specifically, we first review policies at the EU level that provide scope for implementing and targeting of FAB approaches. Second, we describe a selection of FAB initiatives in Europe, and assess their objectives, approaches and progress. Finally, we identify knowledge gaps and provide suggestions to further improve the potential of FAB in European farmland through scientific and policy support.

2. Links with policy

The integration of FAB in agro-ecosystems aligns well with current and planned international policy instruments. Firstly, at the global scale the United Nations Convention on Biological Diversity contains a Thematic Programme on Agricultural Biodiversity (annexed to decision V/5; http://www.cbd.int/decision/cop/?id=7147; 11 October 2012). This Programme recognizes the dilemma of agriculture in that, on the one hand, agriculture may provide essential ecosystem services (such as the production of food and fibre, soil and water conservation, maintenance of soil fertility and biota, and pollination) and, on the other hand, is a major driver of biodiversity loss. In particular those elements in the programme that focus on (i) adaptive management techniques, (ii) practices and policies, and (iii) capacity building, increasing awareness and promoting responsible action can benefit from approaches centred on the conservation and sustainable use of FAB. For instance, FAB practices can be instrumental in conserving and restoring organic carbon in soil and soil structure, conservation and sustainable use of genetic resources, and promoting public awareness of the importance of agricultural biodiversity and its relationship to advancing food security (Brussaard et al., 2010).

Secondly, proposed reforms of the EU Common Agricultural Policy (CAP; Anon., 2010) as per 12 October 2011, which may come into force in 2014, offer opportunities for FAB. At present, the CAP is divided into two main 'pillars', which differ in terms of financing, functioning and structure. Pillar 1 (financed fully from the EU budget) aims to ensure a stable supply of affordable food while ensuring a fair standard of living for the agricultural community. It consists of direct subsidy payments to farmers (income support) and market interventions, such as stock purchases aimed at price stabilization. Pillar 2 – the rural development policy – is co-financed by member states and regional administrations and aims to stimulate the economic, social and environmental development in the countryside. Both pillars have the potential to contribute, directly and indirectly, to conservation of biodiversity and associated ecosystem services. For example, the cross-compliance rules under Pillar 1 focus primarily on preventing environmental damage from farm operations. Under the proposed reforms, FAB could become eligible for 'green' payments aimed at preserving long-term productivity and ecosystems. These direct payments to farmers aim to encourage the improved use of natural resources via crop diversification (farmers will be obliged to grow at least three crops on their arable land, two of which must represent at least 5% of the land each and the third not more than 70%), maintenance of permanent pasture, and the preservation of environmental reservoirs (maintaining an "ecological focus area" of at least 7% of farmland – excluding permanent grassland – through field margins, hedges, trees, fallow land, landscape features, biotopes, buffer strips, and forested area). In particular the ecological focus area offers opportunities for the uptake of FAB measures that may provide direct benefits to the farmer. By selecting the right management practices and/or plant species for non-crop vegetation, these greening measures may provide benefits for both above and belowground biodiversity conservation and sustainable agriculture. Under Pillar 2, biodiversity issues are addressed via targeted instruments, including agri-environmental measures. Here, the European Commission is proposing two specific Rural Development policy priorities (i) for restoring, preserving and enhancing ecosystems, and (ii) for resource efficiency and climate change mitigation. Although FAB and biodiversity conservation have distinct objectives and require different management strategies (Kleijn et al., 2011), and the effectiveness of agri-environmental schemes has been questioned (Kleijn et al., 2006), there is need to assess how synergies between these two objectives can be achieved.

Thirdly, the concept of FAB fits well in EU objectives to minimize the hazards and risks to health and environment exerted by pesticides (Directive 2009/128/EC of 21 October 2009). Targets for the sustainable use of pesticides have now been adopted in Denmark, Sweden, The Netherlands, and Germany via National Action Plans (http://www.pan-europe.info/Campaigns/NAPs.html; 11 October 2012). As growers will have to become less reliant on harmful synthetic pesticides, FAB initiatives that aim to strengthen the ecosystem service of pest control may be an environmentally friendly and more sustainable alternative. FAB measures such as the establishment of nectar-rich flower strips, planting trap crops or conserving non-crop habitats in the landscape have been shown to promote natural enemies and potentially reduce pest populations (Wilkinson and Landis, 2005; Winkler et al., 2006). However, although provision of floral nectar sources and non-crop habitats at the landscape level have generally a positive effect on arthropod natural enemies, this is not always accompanied by suppressed pest populations in crops (Bianchi et al., 2006; Chaplin-Kramer et al., 2011).

Fourthly, FAB can play a role in meeting stringent water quality standards as formulated in the EU Water Framework Directive (Directive 2000/60/EC) by establishment of unsprayed field margins alongside waterways. Indeed, the planting of buffer strips has proven to be effective in reducing pesticide drift and nutrient flows into surface waters (Schulz, 2004; Monaghan et al., 2009). For instance, creation of a 3 m buffer zone decreases drift deposition in the ditch by a minimum of 95%, whereas with a 6 m buffer zone no drift deposition in the ditch could be measured (De Snoo and de Wit, 1998). While the primary purpose of these strips is buffering, these strips can also fulfil other functions, hence offering opportunities for multi-functional habitat use. For instance, when these areas are left untouched or sown with appropriate seed mixtures they may enhance pollinators and/or natural enemies, create habitat for farmland biodiversity, and/or improve landscape aesthetics (see also section about multiple ecosystem services).

Fifthly, the International Treaty on Plant Resource for Food and Agriculture and the European seed legislation (Directive 2009/145/EC of 26 November 2009 and supporting measures) aim to guarantee food security by maintaining local breeds and varieties used in agriculture. These initiatives to safeguard the world's plant genetic resources are a response to the ongoing decline in cultivated plant species. The conservation of crops, varieties and landraces, which are well adapted to local conditions, can support agrobiodiversity and potentially enhance ecosystem services, including pest and disease suppression, carbon sequestration and soil erosion (Hajjar et al., 2008).

3. A selection of FAB projects

There have been numerous initiatives involving FAB across Europe, focussing on a wide array of aspects including above and belowground ecosystem services that benefit agricultural production, environmental quality, the conservation of genetic plant and livestock resources, and associated and wild biodiversity. Here we highlight five examples (Table 1). Cases were selected to capture the (i) diversity of actors (e.g. private companies, governmental organizations), (ii) the diversity of spatial scales considered (e.g. farm, region), (iii) a high level of stakeholder involvement, and (iv) geographic coverage in Europe.

The *Hoeksche Waard* is a 26,500 ha area of polder south of the city of Rotterdam in The Netherlands. It has been a centre for research and implementation of FAB approaches fostered by close interaction among an active group of stakeholders, including farmers, policy makers, researchers, and governmental and non-governmental agencies involved in landscape and water management (Steingröver et al., 2010; Jackson et al., 2012). The main objective of farmers is to become less dependent on the use of (synthetic) insecticides by strengthening the ecosystem service of pest control. To this end, annual and perennial field margins have been established, scouting of crop fields for pests and the restricted use of selective insecticides is promoted, and natural enemy-friendly management of non-crop habitats is encouraged (e.g. dikes, ditch banks). As a result, no chemical insecticide applications

Table 1 – Overview of a selection of FAB initiatives across Europe.

Name	Location	Country	Target ecosystem service	Intervention/ management	Reference
FAB	Hoeksche Waard	The Netherlands	Pest regulation	Perennial grassy field margins, annual flower strips	http://www.spade.nl/ (in Dutch)
Solabio	Flanders	Belgium	Pest regulation, landscape aesthetics, erosion control	Perennial grassy field margins, flower strips, forest edge management	http://www.solabio.org/solabio (in Dutch)
Operation Pollinator	EU	Portugal, Spain, UK, Ireland, Netherlands, Belgium, France, Switzerland, Sweden, Greece, Hungary, Germany, Italy	Pollination	Field margins, flower strips	http://www.operationpollinator.com/
Colworth Farm Project	Sharnbrook, Bedfordshire, England	UK	Pest regulation, water and soil conservation	Mixed rotation, cover crops, hedgerows, field margins	http://www.unilever.com/images/es_Unilevers_Colworth_Farm_Project_2005_tcm13-30020.pdf
Terrana	Western France	France	Pest and weed regulation	Cover crops, mixed cropping	http://www.terrena.fr/index.php?page=nouvelle-biodiversite (in French)

were required in potato and wheat in 4 out of 6 years (pers. comm. J. Willemse). Yet, the economic benefit of saving costs associated with insecticide application does not counterbalance the costs of establishing field margins and scouting, so that subsidies to farmers remain essential (Van Rijn et al., 2011). In addition, farmers have started testing new technologies to optimize farm operations based on the mapped geometry of a field and automated vehicle navigation. Inefficient use of the land can thus be avoided and remaining parts of the parcels can be used to implement FAB (De Bruin et al., 2009). Furthermore, GPS-controlled traffic and reduced tillage practices are used to promote soil biodiversity and associated functions by minimizing soil disturbance and restricting soil compaction to traffic lanes. The concentration of a range of FAB-related interventions at a landscape scale makes this case study unique and offers opportunities to benefit from mutually strengthening functions such as arthropod-mediated ecosystem services, landscape aesthetics and conservation of farmland biodiversity.

The *SOLABIO project* (October 2008–March 2012) was conducted in the framework of the EU INTERREG IVA programme and united 27 stakeholders from five Flemish and three Dutch provinces. The project aimed to prevent the degradation of biodiversity and valuable landscapes in the Flemish–Dutch border region. This was operationalized by a wide range of activities targeting crop and non-crop habitats, including the establishment of field margins. Annual flower strips attracted flying nectar-feeding natural enemies, and grassy field margins harboured a diversity of ground-dwelling predators which are associated with the regulation of aphid populations in crops. Scouting of aphid and natural enemy populations in crops indicated that current economic damage thresholds for insecticide application are too low to allow for effective natural pest regulation. Perennial grass strips also provided erosion control, and both annual and perennial field margins contributed to the conservation of farmland biodiversity. For instance, in grassy field margins 89 species of ground beetles were found, including 23 rare and protected species (http://www.solabio.org/solabio/;17 October 2012, in Dutch)

Operation Pollinator is an international 5-year biodiversity programme initiated by the agro-business company Syngenta. The programme aims to boost the number of pollinating insects on commercial farms by creating specific habitats, tailored to local conditions and native insects. Operation Pollinator is informed by scientific research and experience of selected farmers, and has helped growers to successfully establish and manage pollen-rich habitats around the farm. Independent monitoring indicated that these habitat manipulations can lead to a 6-fold increase in bumblebee numbers, a 12-fold increase in butterfly numbers and a more than 10-fold increase of other insects within three years (http://www.operationpollinator.com/; 11 October 2012). Building on the success of Operation Bumblebee in the UK, Operation Pollinator is now being developed on 2000 ha of commercial farms across Europe, involving about 2500 farmers in 13 European countries (Table 1). The project is supported by a large number of partners such as universities, beekeeper and farmer associations, governmental bodies, NGO's, retailers and food producers. The project demonstrates that environmental management and economically viable intensive agriculture can coexist in the same field and benefit each other.

The *Colworth Farm Project* in Bedfordshire, UK, is part of the Sustainable Agriculture Initiative of the consumer goods company Unilever. From 1999 to 2006, a 60-ha section of the farm was used as an experimental station. The aim of the project was to develop sustainable production systems for peas and oilseed rape within a six-year commercial rotation. Practices developed during that period have been continued since. The project focused on examining the impact of spring versus winter cropping, reduced nitrogen input, use of cover crops, reduced pesticide applications, mechanical weeding and field margin management. To assess the impact of the various management strategies, the project team monitored the abundance and diversity of birds, plants and insects, the concentration of nitrate, phosphate and pesticides in surface water, as well as crop yields and profits. The environmental, financial and social costs and benefits of adopting potentially more sustainable practices have been assessed and improvements identified. For instance, (i) spring cropping offered environmental benefits through reductions in agrochemical input, elevated bird abundance and improved potential for weed control, (ii) reduced nitrogen inputs reduced crop yield, but also reduced the potential for nitrogen leaching and improved weed control, (iii) band spraying was more effective in reducing pesticide leaching than reducing application rates, and (iv) although experimental yields were in some cases reduced by up to 60%, in other cases wheat yields were comparable with those managed conventionally, and often provided better gross margins (http://www.unilever.com/images/es_Unilevers_Colworth_Farm_Project_2005_tcm13-30020.pdf; 11 October 2012).

Terrena is the largest French agricultural cooperation consisting of 22,000 farmer members and covering 2 million ha in Western France. The *Terrena Vision 2015 project* aims to reduce the dependency on artificial and non-renewable inputs by integrating FAB in the current production systems. Examples of current work include (i) mixed cropping of ultra-early green rape with oilseed rape at 8500 ha to reduce crop injury by pollen beetles in oilseed rape and reducing the need for insecticide applications, (ii) suppressing weeds by the use of leguminous cover crops resulting in a reduction of herbicide use by 66%, and (iii) establishing flower strips in vineyard rows to enhance natural enemies of the grape berry moth. While it is recognized that the FAB approach entails more risk than the conventional agrochemical approach, it is also recognized that it is compatible with the conservation of biodiversity at the field and landscape scale. The development and testing of new FAB approaches by farmers and Terrena advisors is ongoing. (http://www.terrena.fr/index.php?page=nouvelle-biodiversite; in French; 11 October 2012).

While these case studies play an important role in the indispensable translation of general knowledge to tailored, ready-to-use management practices, limited information is available on the effectiveness of the programmes in terms of crop yield and quality, profitability, and reduction of agrochemical inputs (but see The Colworth Farm Project for an exception). Although this can be explained by the fact that most projects are still in the pioneering stage, such information is critical for the assessment of the prospect of the measures. We suggest that the monitoring should not be limited to the ecological aspects of the interventions, but that the assessment of the appropriate agronomic and economic indicators should become an integral part of FAB projects.

4. Future management needs for FAB

4.1. *Landscape context of FAB*

FAB practices are typically implemented at the field and farm scales as convenient management units for the individual farmer. However, the spatial scales at which organisms involved in the delivery of ecosystem services and dis-services operate often differ from these management scales, for instance mobile taxa operate at landscape scales and beyond (Schellhorn et al., 2008; Gabriel et al., 2010). As a consequence, the effectiveness of FAB programmes implemented by individual farmers will also be influenced by the management practices of surrounding farms and the landscape context in general (Brittain et al., 2010). Conversely, reaching environmental and biodiversity targets at regional scale depends on management at farm and field scale. For instance, flower-rich field margins for attracting pollinators and natural enemies may not be effective if surrounded by fields frequently sprayed with broad-spectrum insecticides or when there are no source populations of beneficial organisms in the wider surroundings. Hence, FAB measures need to be implemented at the right spatial scale(s). Although implementing FAB programmes beyond the farm scale requires cooperation between multiple actors and stakeholder groups, there are compelling examples that such concerted action can be successful, such as in the Hoeksche Waard in The Netherlands (Steingröver et al., 2010).

Landscape-scale FAB approaches require understanding of the role of various habitats and management practices in the landscape mosaic in supporting organisms that are instrumental in ecosystem service and dis-service delivery. For instance, the proportion and spatial distribution of susceptible and resistant crops in the landscape is likely to be a key factor for the incidence of air-borne diseaseses (Skelsey et al., 2010). There is growing evidence that natural enemies and pollinators generally show positive responses to non-crop habitats (Ricketts et al., 2008; Chaplin-Kramer et al., 2011), but this is less clear for seed predators, such as rodents, ants, carabid beetles and birds, which can play a role in the suppression of weeds in arable fields (Petit et al., 2011). Furthermore, it has been postulated that increasing the diversity of crops and implementation of biodiversity-friendly crop management practices may also have potential to enhance biodiversity and associated ecosystem services (Fahrig et al., 2011). While such crop diversification approach would be advantageous for reconciling food security and biodiversity conservation (Tscharntke et al., 2012), the general applicability of this premise still needs rigorous testing (Jackson et al., 2012).

The implementation of FAB and the spatial planning of ecosystem services require information on thresholds in habitat availability for obtaining desired levels of ecosystem service delivery. A question frequently posed by farmers is: "How much of my land should I dedicate to refuge habitat to support beneficial biota?". The exact relationship between habitat area and ecosystem service delivery will depend on a wide range of factors, including the area and spatial arrangement of source habitats (Holzschuh et al., 2010), species characteristics, such as dispersal capacity (Bianchi et al., 2010), habitat quality (Kleijn and van Langevelde, 2006) and interactions between agricultural management and landscape characteristics (Haenke et al., 2009). As a consequence, setting minimum area requirements for habitat provision is context-specific. However, as a rough guideline, the potential of adequate pest control and pollination below a proportion of permanent non-crop area of 5% seems to be limited (Manhoudt and de Snoo, 2003; Kleijn and van Langevelde, 2006). At the other end of the spectrum, a level of 20–30% non-crop habitat has been suggested as a threshold at which further increases in non-crop habitat have limited further positive effect on farmland biodiversity, pollination and pest control services (Banaszak, 1992; Tscharntke et al., 2002; Morandin and Winston, 2006). While the integration of large areas of non-crop habitats will require more land allocated to agriculture to maintain current production levels, the benefits of integrating biodiversity in agro-ecosystems or separating nature and agriculture is under debate (Phalan et al., 2011; Tscharntke et al., 2012). Yet, precision agriculture offers scope to effectively use land for crop production and allocate strips and inaccessible corners to agrobiodiversity (De Bruin et al., 2009). In conclusion, the landscape context dependency of the effectiveness of FAB programmes indicates that there is scope for prioritizing areas where investments are likely to be best suited to capitalize on the associated ecosystem services (Tscharntke et al., 2005).

4.2. *Managing for multiple ecosystem services*

The majority of studies and programmes on FAB focuses on a single or limited set of ecosystem services. While the complexities of the interactions between plants and other biota underlying ecosystem services provision often promote reductionist research approaches, it is the combined set of ecosystem services provided by FAB interventions that determines the ultimate benefit to farmers and society as a whole. Therefore, the identification of management options that simultaneously enhance multiple ecosystem services is desirable (Gurr et al., 2003).

One approach towards diversified agro-ecosystems is to improve resource availability that benefits a wide range of taxa, such as establishment of native plants for arthropods (Isaacs et al., 2009). However, care is needed not to enhance potential harmful species, such as agricultural pests (Winkler et al., 2003). As particular guilds of insects are selective in the plant species from which they obtain nectar and the desired flower species may be easily excluded by more competitive plant species, the selection of appropriate flower mixtures for flower-rich field margins requires careful screening. Another consideration for selecting plant species is the choice between annual and perennial plants. Flowering annual plant species are often better in providing nectar and may have a higher aesthetic value, whereas perennial species provide a better microclimate for hibernation, prevent soil erosion throughout the year and may be more suitable for biodiversity conservation.

Another approach, which has attracted less attention and is still in its infancy, is to manage for above and belowground ecosystem services simultaneously. Creating non-crop habitats such as field margins does not only provide refuge for aboveground, but also for beneficial belowground biota, such as earthworms (Smith et al., 2008; Nuutinen et al., 2011). Conversely, tailored soil management has been shown to result in improved biocontrol of above ground pests (Hokkanen, 2008; Rusch et al., 2012). While earthworms have been associated with enhanced N-mineralization (Lubbers et al., 2011) and improving soil structure (Jongmans et al., 2003; Pulleman et al., 2003), the low horizontal colonization rate of soil organisms indicates that the spatial and temporal scales to influence belowground ecosystems can differ orders of magnitude from aboveground ecosystem services mediated by more mobile organisms. Hence, manipulation of belowground ecosystem services can also benefit from complementary interventions conducted at the field scale, such as minimum or no tillage and organic manure amendments (Ernst and Emmerling, 2009; Nieminen et al., 2011). As soil fertility and soil health associated with belowground ecosystem services is essential for providing food security in a sustainable fashion, management for above and belowground ecosystem services is likely to receive further scientific attention.

5. Synthesis and conclusions

Although the concept of FAB is adopted by a group of front-running farmers and land managers, it is still mostly in the pioneering stage and the step towards general adoption yet needs to be made. The implementation of FAB concepts is hampered by several factors. First, there is still limited information available on the implications of FAB measures in terms of changes in crop yield and quality, profitability, and reduction in agrochemical input, as compared to conventional management. Although reports are generally positive about achievements, this is rarely underpinned by a rigorous economic and agronomic analysis. Hence, improved monitoring and evaluation of appropriate indicators is key to provide a convincing case of the potential of FAB. As long as financial and agronomic risks associated with implementation of FAB measures are not clear, large-scale adoption of such measures is not likely to take off. Second, there is a need to put appropriate financial accounting systems in place of private investments made by land managers and public benefits provided to society as a whole (CREM, 2008). For instance, in The Netherlands the cost of establishment of field margins and scouting for pest populations in crops do not outweigh savings on pesticides, so that farmers still rely on subsidies, even if pesticide use is limited to a minimum (Van Rijn et al., 2011). Yet, such management is likely to provide other services which are currently not valuated but may justify compensation from public sources (e.g. reduction of water pollution, increased biodiversity, recreational value of rural landscapes). Third, despite of the growing body of scientific research, the translation of knowledge to management practices tailored to (landscape-) specific situations and the subsequent integration on farms is still a limiting factor. Programmes specifically focussing on putting knowledge into practice by participatory approaches can aid in developing FAB ‘toolkits’ tailored to local conditions. Finally, our literature review suggests that landscape approaches have superior potential to support mobile agent mediated ecosystem services than uncoordinated approaches at the field and farm scale, and that synergies can be created between the promotion of biodiversity and ecosystem services above- and belowground. Such concerted action requires coordination among stakeholder groups. The appointment of a regional orchestrator that is supported by all relevant stakeholders may be a promising strategy to organize regional incentives (Van Alebeek et al., 2011).

These current limitations could be addressed in policy by explicitly recognizing farmers not only as food producers, but also as providers of public goods. This can be materialized by:

- Linking payments for ecosystem services to the value of the public goods provided by the farmers rather than the size of the cultivated area.
- Guaranteeing proper public payment for delivering public goods and services by ensuring clear economic benefits for farmers and eligible subsidies, for instance by integration of FAB in Pillar 2 of CAP and/or link FAB to Pillar 1.
- Improving rural development and agri-environment schemes to deliver more towards environmental objectives and ecosystem services, and involving stakeholders, including farmers, environmental experts, and scientists in their development.
- Stimulating a flexible implementation of FAB to account for local conditions and at appropriate spatial scales.
- Increasing awareness of the potential of FAB by setting up training and education programmes.

Incentives that address current limitations can contribute to the further development and implementation of FAB measures based on the conservation and sustainable use of biodiversity and associated ecosystem services, and as such contribute to sustainable agricultural production.

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