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Functional Biodiversity in Organic Systems: The Way Forward?

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Abstract

Trends in EU agricultural policies recognize an increasingly important role to biodiversity conservation and use in agroecosystems, including organic ones. However, along with their economic success, organic systems are facing a risk of 'conventionalization', i.e. the prevalence of input substitution over agroecologically-based crop management. Understanding what is functional agrobiodiversity and when it can be successfully applied in organics may help strengthen the recognition of organic farming as the reference management system for agricultural sustainability. Here functional agrobiodiversity is defined as a subset of total biodiversity identified at the gene, species or habitat level able to deliver a given agroecosystem service, which extent increases with diversity in the functional group. Different functional agrobiodiversity categories are identified, compared to biofunctionality, and used to illustrate the mechanisms through which they can support agroecosystem services and consequently sustainability. Three case studies taken from the author's own research are used as examples to illustrate functional agrobiodiversity's potential in organic systems as well as open questions. Results show that (i) functional agrobiodiversity has potential to support agroecosystem services but it is not possible to generalize the effects; (ii) a given functional biodiversity element may create conflicts between different target agroecosystem services. In those cases, prioritization of services is required.

Keywords: agroecology, agroecosystem service, biological pest control, field margin, mycorrhizae, weed management

1. Introduction

1.1 Scope and Structure of the Paper

This paper aims to highlight the potential of functional biodiversity to improve organic farming and strengthen its recognition as one of the best models for sustainable agriculture. The paper is structured in four parts. In the first I will present the current trends in sustainable agriculture policies, with special reference to the European Union (EU), and the threats organic farming may face if it rests on its laurels. In the second part I will synthesize the relationships between agriculture and biodiversity as perceived by researchers with different backgrounds and by EU policy makers. In the third part I will provide a working definition of functional biodiversity, illustrate its typologies and present three case studies from our research showing different effect types. In the last part I will draw some conclusions and highlight the links between functional biodiversity and sustainability and recognition of organic farming systems.

2. Trends in EU Sustainable Agriculture and Threats to Organic Farming

There is an ongoing worldwide debate on agricultural sustainability, showing that sustainability priorities may differ among geographical areas. In the last two decades, the EU has decidedly steered its Common Agricultural Policy (CAP) towards the reduction of chemical inputs such as fertilizers and pesticides and the promotion of alternative production methods like organic farming. This trend has recently been reinforced by two important policy decisions. The first is the EU Directive on Sustainable Pesticide Use (European Union, 2009) which states that, from 1 January 2014, all EU farmers should use approaches and methods of Integrated Pest Management (IPM) as their reference way of farming. The second is the new CAP, in place from 1 January 2015, and especially its 'greening' component, which allocates at least 30% of the total subsidies to farmers who are willing to increase on-farm crop diversification and use part of their cropland for ecological infrastructures such as hedgerows, field margins or permanent pasture (http://ec.europa.eu/agriculture/cap-post-2013).

According to the new CAP organic farmers are considered by definition 'green' and hence eligible to those subsidies without further commitment. However, this poses for them the risks of neglecting the importance to improve their environmental sustainability and being tempted to take management shortcuts which may undermine the organic production philosophy. In fact, the difference between prescriptions for IPM farmers (upon the EU Directive on Sustainable Pesticide Use) and for organic farmers (upon the EU Regulation on Organic Farming) is shrinking, thus potentially diminishing the recognition of organic farming as likely the most environmentally-friendly production method. Also, the growing economic success of organic farming increases the risk of 'conventionalization' of organic production practices (Best, 2008; Darnhofer et al., 2010), e.g. simplification, over-reliance on input substitution, and neglection of the importance of the system approach as the best way to ensure long-term soil fertility and reduce pressure from pests, diseases and weeds. If organic products become too similar to conventional or IPM ones why should consumers continue to buy them? This is an issue that needs to be urgently addressed. I propose that application of functional biodiversity in organic systems, once properly defined and turned into practical tools, would not only contribute to increased sustainability but also diminish the risk of conventionalization and the consequent negative implications for the organic sector's recognition.

3. Agriculture and Biodiversity: A Fuzzy Picture

It is well known that agriculture can support biodiversity ('A for B') and biodiversity can support agriculture ('B for A') (Bàrberi et al., 2010), yet the importance of balancing these two approaches is rarely taken into account (Altieri, 2004). This partly derives from the differential importance given to them by ecologists and conservation biologists on one hand and agriculturalists on the other, which is often reflected by dichotomy in the scientific literature (see e.g. Moonen and Bàrberi, 2008 and references therein), but also from the lack of a comprehensive definition of agricultural biodiversity (hereafter 'agrobiodiversity'). For instance, the OECD definition of agrobiodiversity (Parris, 2001), strictly linked to the approach of the United Nation's Convention of Biological Diversity (CBD), does not mention at all crop sequence diversification (e.g. longer rotations, use of cover crops, intercropping and other types of polyculture) among the examples of agrobiodiversity at species level. In contrast, the approach of Agroecology to farming clearly identifies cropping system diversification in time and space as the starting point to redesign agriculture in a sustainable, environmentally-friendly way (Altieri, 1995).

It has long been recognized that, unlike conventional farming, organic farming does care for biodiversity. This issue, however, is often addressed in general terms without clearly distinguishing between production-related agroecosystem services (e.g. crop yield, soil quality, biological pest control) and non production-related ones (e.g. species and habitat conservation, recreational and cultural values) provided by biodiversity. There is not always a clear relationship between biodiversity and the expression of (agro) ecosystem services (Bengtsson, 1998) hence mixing up production- and non production-related services does not help shed light on it. A clearer theoretical framework highlighting the potential of biodiversity to support agroecosystem services is therefore needed. This would help identify which approaches and practical solutions are feasible in any given context. In turn, this would increase the probability of adoption from organic farmers and policy makers, thus contributing to keeping the recognition of organic farming as the most environmentally-friendly production method.

In the EU, the 'A for B' approach has largely dominated in the last decade, both in science and in policy. This is likely due to a stronger perception of the negative environmental effects of intensive agriculture than in other parts of the world, pushed by evidence like the ca. 30% decline in farmland bird populations observed in the UK between 1980 and 2002 (Birdlife International, 2004). The EU agri-environmental schemes (AES), set forth in the early 1990s as part of the CAP, provide financial support to farmers engaged in setting aside part of their land from production and/or introducing specific measures for the conservation of wildlife species and habitats in cropland. Despite considerable financial effort, AES have had dubious effects, likely because the measures were not focused enough and were too little grounded on sound ecological theory (Kleijn & Sutherland, 2003). In contrast, the 'B for A' approach – a pillar of Agroecology – despite having recognized importance for organic farming management worldwide (e.g. in the IFOAM principles) has so far mainly been applied to small scale farming in developing countries (Altieri, 2009), although application in the developed world is progressing. What is currently missing is a clear recognition of the fact that production- and non production-related agroecosystem services are not always competing and that both views can be embraced in a comprehensive definition of functional biodiversity.

4. Functional Biodiversity: Definition and Typologies

Functional biodiversity has been defined in various ways in the scientific literature (see e.g. Pearce & Moran, 1994, Gurr et al., 2003; Clergue et al., 2005) but here I am relying on our own definition, upon which we consider functional biodiversity as that part of total biodiversity composed of clusters of elements (at the gene, species or habitat level) providing the same (agro) ecosystem service, that is driven by within-cluster diversity (Moonen & Bàrberi, 2008). The latter specification is crucial and distinguishes functional biodiversity from biofunctionality, in which the effect of diversity in the functional group (cluster) linked to a given agroecosystem service is disregarded. As an example, if I say that ladybirds predate aphids I am only referring to their biofunctionality whilst if I say that a higher number of ladybird species predate a higher number of aphids I am referring to their functional biodiversity.

In a more recent paper (Costanzo & Bàrberi, 2014) we have refined our definition of functional biodiversity by identifying three categories: (i) *functional identity*, i.e. the presence of a set of homogeneous phenotypic traits that are related to the expression of a given agroecosystem service (e.g. a smothering cover crop); (ii) *functional composition*, i.e. the complementary effect of different traits, expressed by co-occurring elements, on the provision of a given agroecosystem service (e.g. intercropping or variety mixtures), and (iii) *functional diversity* (*sensu stricto*), i.e. the direct effect of heterogeneity within a single crop stand on the expression of a given agroecosystem service (e.g. a wheat composite cross population). We believe that linking crop traits to agroecosystem services should help identifying suitable biodiversity-based options for farmers and policy makers.

Hereafter I present three case studies taken from our research on functional biodiversity in organic agriculture, showing the different effects that biodiversity components can have on the expression of agroecosystem services.

4.1 Case Study #1: Agroecosystem Service Provided by Biofunctionality (No Effect of Functional Biodiversity or Functional Identity)

A pot experiment under greenhouse conditions was set up to investigate the influence of presence and diversity of arbuscular mycorrhizal fungi (AMF) on sunflower growth and weed suppression (Rinaudo et al., 2010). The research hypotheses were that (i) presence of AMF should promote sunflower growth and hence reduce weed biomass (= biofunctionality effect) and that (ii) these effects should be enhanced by the diversity in the AMF community (= functional biodiversity effect). The effect of AMF species (= functional identity) was unknown. Details on treatments are provided in Table 1. When sunflower competed with weeds, total weed biomass was reduced by ca. 40% in the pots where AMF were present, regardless of AMF species (functional identity) and AMF species number (functional biodiversity). Also, AMF presence (all species together) reduced total weed biomass by 25% when weeds did not compete with sunflower. Here, we only detected a biofunctionality effect (the presence of AMF did suppress weeds) but neither a functional identity nor a functional biodiversity effect (all species of AMF were alike and AMF species richness did not increase the weed suppression effect).

4.2 Case Study #2: Agroecosystem Service Provided by Functional Biodiversity (Functional Identity)

A field experiment embedded within the MASCOT long-term experiment (Pisa, Italy) was carried out to investigate the effect of genetic and species diversity on AMF abundance and organic corn performance (Njeru et al., 2014). The research hypotheses were that (i) increasing genetic and species diversity should provide a more favourable environment for AMF activity under organic management, and that (ii) higher genetic and species diversity should improve AMF colonization and consequently maize early growth. Details on treatments are provided in Table 1. Presence of cover crop was beneficial for AMF soil colonization and there was a clear effect of cover crop treatment (*Vicia villosa* > mixture > *Brassica juncea* = control). In turn, higher AMF colonization was positively correlated with corn early growth (shoot dry weight) although the rate of corn biomass increase with % AMF colonization differed between years. In contrast, corn genotype diversity did not show any significant effect. Here, we detected both a biofunctionality effect (presence of cover crops increased AMF colonization which in turn increased corn biomass) and a functional biodiversity effect but only in the case of the cover crop factor. In details, the positive effect of the latter was linked to functional identity (cover crop species) but not to functional composition (the cover crop mixture was not the best treatment). In the case of the corn cultivar factor, the hybrids had the same effect of composite cross population, i.e. no functional diversity effect (as defined earlier) was detected.

4.3 Case Study #3: Agroecosystem Services Potentially Increased or Reduced by the Same Functional Biodiversity Element

A landscape scale study (Moonen et al., 2006) was carried out to investigate the effect of the structure of field margin complexes (FMC, i.e. any non cultivated element comprised between two adjacent cultivated fields) in the arable part of an organic farm on wild flora diversity in the FMC and its effect on arable weed suppression and abundance of aphids' natural enemies (Coccinellidae, Syrphidae and Chrysopidae). The research hypothesis was that a more complex (heterogeneous or diverse) habitat structure surrounding arable fields should (i) reduce weed presence in the FMC and hence risk of weed invasion in the field, and (ii) encourage presence of natural enemies of aphids. FMC heterogeneity can e.g. be related to presence of different vegetation types and/or layers, to FMC width and to its management. Details on the survey are provided in Table 1. Wild flora diversity showed a large variation across the 62 FMCs (α diversity from 10 to 54 species and weediness from 32 to 88%). FMC structural complexity was positively correlated with wild flora diversity which in turn reduced % weediness in the margins. However, abundance of natural enemies was negatively correlated to FMC complexity and wild flora diversity and positively correlated to % weediness in the margins, likely because natural enemies use weeds as alternative feed, shelter and/or reproduction site. Here, we detected a functional biodiversity effect (linked to FMC complexity) which, however, was of opposite sign depending on the target potential agroecosystem service (positive for weed suppression and negative for biological pest control).

Table 1. Synthesis of the three case studies, indicating (i) type or scale of experiment, (ii) experimental material and treatments, (iii) detection of biofunctionality effect[1] (yes/no), (iv) detection of functional biodiversity effect[1] (yes/no), (v) reference

Type/scale	Material/treatments	Biofunctionality effect	Functional biodiversity effect	Reference
Pot	Three species of AMF[2] (*Glomus mosseae*, *G. coronatum*, *G. intraradices*); six weed species (*Setaria viridis*, *Echinochloa crus-galli*, *Digitaria sanguinalis*, *Sinapis arvensis*, *Chenopodium album*, *Amaranthus retroflexus*), one crop species (sunflower). Nine treatments: sunflower + all weeds + each AMF species *or* all AMF species *or* no AMF; sunflower + all AMF *or* no AMF (without weeds); weeds + all AMF *or* no AMF (without sunflower); completely randomized design	Yes	No	Rinaudo et al. (2010)
Field	Three preceding cover crops (*Brassica juncea*, *Vicia villosa*, a mixture of 7 species) + a no cover crop control x five corn cultivars (one conventional hybrid, one organic hybrid, three organic composite cross populations); split-plot design	Yes	Yes (identity) for cover crop factor No for cultivar factor	Njeru et al. (2014)
Landscape	Sixty-two field margin complexes (FMC) classified in terms of structural complexity (ecological niches), management, and disturbance upon a FMC Integrity Index. Vegetation in the FMC was classified in five groups (woody species, grasses, herbaceous dicots, grass weeds, dicot weeds). Eight of the 62 FMC were also sampled for natural enemies abundance	Yes	Yes (positive on weed reduction, negative on abundance of natural enemies)	Moonen et al. (2006)

[1]As based on statistical significance after ANOVA ($P \leq 0.05$), [2]AMF = arbuscular mychorrizal fungi.

5. Conclusion

Results of the three case studies clearly show that practical solutions based on the application of functional biodiversity do exist and can make organic systems more sustainable by increasing soil fertility and reducing abundance of biotic aggressors. Interestingly, effective solutions can be found at any of the three recognized levels of agrobiodiversity (genetic, species and habitat), and is likely that success stories would mainly be found where two or all levels are combined (Bàrberi, 2013). Another benefit often linked to higher functional agrobiodiversity is increased crop resilience against abiotic stresses, e.g. climate change (PAR, 2010). In a wider perspective, additional benefits that can be envisaged are increased resistance against the temptation of organic farmers to walk the pathway of 'conventionalization' and consequently against loss of trust from consumers.

However, it should be pointed out that generalizations on the effects of functional agrobiodiversity should be avoided. The third case study presented here shows that, although provision of multiple agroecosystem services from the same functional element is desirable, it cannot always be attained due to existing conflicts between services. This calls upon the need to clearly prioritize services on a case by case situation and search for functional agrobiodiversity-based best practices accordingly.

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