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Legume Crops and Biodiversity

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Abstract

Modern intensive cropping systems rely on simple cropping sequences, mineral fertilizers and chemical crop protection. This has led to a reduction of crop diversity, simplified landscapes and declines in biodiversity. However, even today in intensive farming systems, legume-supported cropping has the potential to deliver many ecosystem services, both directly due to unique trait combinations and indirectly via promoting biodiversity and by facilitating services such as pollination, pest control and soil improvement. This chapter outlines the effects of legume cropping on biodiversity, focusing on legume-specific traits and their interactions with agricultural management. Legumes have complex direct and indirect interactions with the surrounding agroecosystem and its management, so it is not possible to fully separate general crop management effects from effects of management that is specific to legume crops, and legume-trait effects. Legumes can benefit farmland biodiversity when included in highly productive cropping systems. Legume crops qualify for the ecological focus areas in 'greening' of the Common Agricultural Policy (CAP) of the European Union (EU). Several of the effects of legumes are related to changes in management practices, such as a reduced use of pesticides, fertilizer or soil tillage. Of course benefits for biodiversity may be also partially achieved by other crops and diversified crop rotations. However, legume traits and management practices vary at a species or even cultivar level and so here we provide a general overview of the effects on biodiversity.

Introduction

Agroecosystems are characterized by more frequent disturbance of vegetation than occurs in most natural and semi-natural ecosystems. Crops are communities of plants that are simplified by weed control and fertilization (Tilman *et al.*, 2002). Additionally, agricultural management affects many non-crop species via

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addition (fertilization) or removal of organic material (harvest), regular soil disturbance (tillage, compaction), and the use of crop protection products. This reduces the ability of ecosystems to provide goods and services (Tilman *et al.*, 2002). The use of legumes to diversify cropping systems and simultaneously support species conservation and food security requires an understanding of the underlying mechanisms that generate and maintain diverse and productive agroecosystems. As dicotyledonous, mass-flowering and nitrogen-fixing plants, many legume species are different from non-leguminous mass-flowering crops such as oilseed rape (*Brassica napus ssp. napus*) or sunflower (*Helianthus annuus*). Grain legumes (e.g. soybean, *Glycine max* Merr) or faba bean (*Vicia faba*) and forage legumes (e.g. lucerne (alfalfa), *Medicago sativa*; and clovers, *Trifolium spp.*), as 'catch', 'cover', 'green manure' or 'alternative host' intercrops vary in their characteristics and accordingly in their impact on the agroecosystem and surrounding landscapes. Yet to harness potentially positive effects, the agricultural management as well as the trait combination and expression of the specific legume crop must be considered (Fig. 4.1).

How Legume Traits Influence Local Biodiversity on Farmed Land

Research into effects on biodiversity has focused predominantly on natural or semi-natural ecosystems. In farmed ecosystems, biodiversity is vital for the supply of supporting and regulatory ecosystem services, including pollination, nutrient cycling, soil structure and functioning, hydrological processes and crop protection (Tscharntke *et al.*, 2005; Altieri and Rogé, 2010) if provisioning services (crop production) are to be maximized (Tscharntke *et al.*, 2005; Altieri and Rogé,

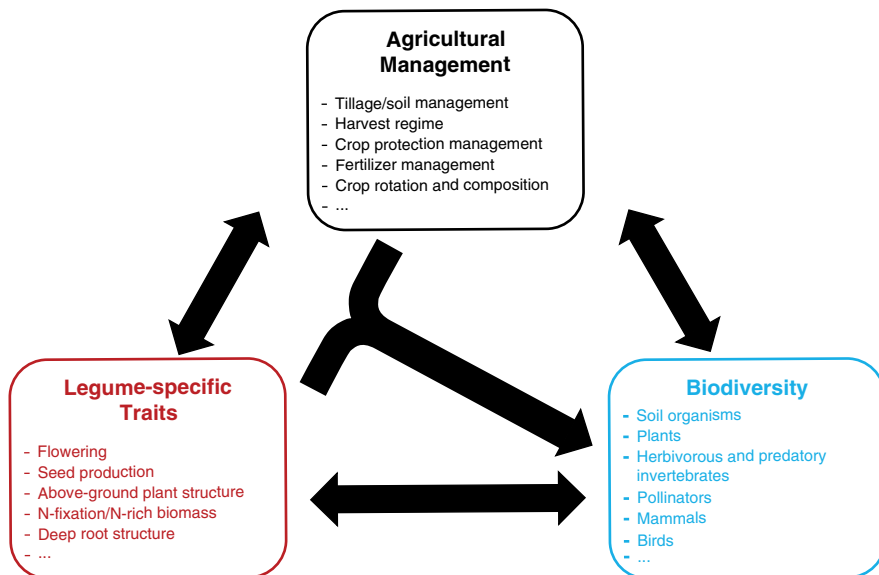


Fig. 4.1. Potential effects and interactions between legume traits, agricultural management and biodiversity in legume-supported cropping.

2010). In both natural and farmed systems, several legume traits, such as mass-flowering, biological nitrogen fixation (BNF), weed suppression, niche generation or soil improvement often act in combination to affect biodiversity. However, for an understanding of the effects of legumes on biodiversity, it is useful to consider these traits separately, also because they differ between legume species in their combination and expression.

Flowering and pollination

The characteristic floral morphology of most legumes, comprising a long corolla, curved nectar tube and bright colour is widely considered to have contributed to the rapid divergence of this plant group and co-evolution with specific pollinators (Leppik, 1966) (Fig. 4.2). As a result, flower-feeding insects of the order Hymenoptera, whose proboscis and feeding strategies have evolved in tandem with the pollination requirements of legume flowers, benefit from legume-rich grass and forage systems. Studies have shown that the floral abundance, species richness and the availability of nectar and pollen, especially in the form of legumes, can drive bumblebee community composition and can enhance pollinator populations (Potts *et al.*, 2009).

Pollinator decline has been driven in part by habitat loss, reducing the abundance and diversity of floral resources and nesting opportunities (Goulson *et al.*, 2015). In addition, pollinators have been exposed to cocktails of agrochemicals and other changes in agricultural practices (Goulson *et al.*, 2015). As a consequence of declines in pollinator abundance and diversity, seed yields can decline, for example, in red clover (*Trifolium pratense*) (Bommarco *et al.*, 2012). To conserve and promote bees and local pollination services, field margins sown with the legume-based pollen and nectar mixture have been shown to be beneficial in terms of attracting bees (Carvell *et al.*, 2007; Woodcock *et al.*, 2014), although legume flowers are not a suitable resource for many non-bee pollinators. Therefore, planting legumes could enhance bee populations in some contexts (Scheper *et al.*, 2013), aid conservation efforts and simultaneously improve crop yields (Palmer *et al.*, 2009). Additionally, many legumes provide extra-floral nectar, which is accessible to many invertebrates, including beneficial species such as parasitoid wasps (Géneau *et al.*, 2012). Not all legumes depend on bee-mediated pollination or



Fig. 4.2. Honeybee (*Apis mellifera*) foraging on lucerne (*Medicago sativa* subsp. *varia*). (Photo credit: Christine Venjakob.)

provide sufficient amounts of accessible nectar and pollen to be visited by foraging bees (e.g. pea, *Pisum sativum*; or lentil, *Lens culinaris*) (see Chapter 5, this volume), or produce resources throughout the season. Thus a positive effect of legumes on pollinator abundance and diversity depends on the legume species and whether its rewards can be utilized by a particular species or not (Palmer *et al.*, 2009; Mader and Hopwood, 2013). On a broader scale, this may also influence the pollination of other flowering plants, including other crops, either by facilitating pollination in other species by attracting additional pollinators, or by competing for pollinators (Brookes *et al.*, 1994; Ghazoul, 2006).

There are calls for altering crop breeding targets to improve additional environmental functions and support better integration of crops into healthy agroecosystems (Palmer *et al.*, 2009). Selection for traits to improve floral attractiveness, including colour, morphology, phenology and the quantity and quality of nectar and pollen rewards for pollinators is an area in which crop breeding strategies could make gains while simultaneously improving crop productivity through increased cross-pollination and hybridization (Palmer *et al.*, 2009). Self-pollination has been promoted in many grain legumes such as soybean during their domestication (Mader and Hopwood, 2013). However, out-breeding remains the dominant mode for the majority of forage legumes and other species not predominantly bred for seed production (Carbonero *et al.*, 2011).

Biological nitrogen fixation

The nitrogen (N)-rich root, shoot and leaf biomass of legume crops, enabled by BNF, increases the availability of N to neighbouring or succeeding non-legume crop plants (Kumar *et al.*, 1999). Decomposer communities, microorganisms, dependent fauna and herbivores play an important role in recycling plant litter and making the fixed N available to surrounding plants. For example, the N transfer from clover to wheat is related to earthworm activity (Schmidt and Curry, 1999). Root exudates as well as living and senescent root biomass provide additional below-ground N-enriched input to the soil (Sugiyama and Yazaki, 2012). Through subsequent trophic interactions, these N-rich resources are transferred throughout the food web. This may increase plant density and unsown vegetation biodiversity, although this may not be the case in highly fertile managed agricultural grasslands where nitrogen is not a limiting nutrient (Tilman *et al.*, 1997).

The low C:N ratio of legume biomass can also influence higher trophic levels by providing high-quality, accessible nutrients (Sileshi and Mafongoya, 2007). This is available to all invertebrate herbivores, so it benefits pest species as well as those with neutral or positive impacts on crop productivity. Thus without a diverse and well-structured community of invertebrates and other organisms on farms, the attractiveness of legumes could have a detrimental effect on production in cropping systems by attracting herbivores that may spill over into both legume and non-legume crops and become pests. In a healthy ecosystem, increased pest populations also lead to increased predator and parasitoid populations, supporting equilibrium between pests and natural enemies (Price *et al.*, 1980).

Increased diversity and other changes to the non-crop vegetation and invertebrate community, resulting not only from legume cropping, can also benefit farmland bird populations by promoting species upon which their diets rely (Moorcroft *et al.*, 2002).

N-rich legume plant material used as a green manure crop or present as litter increases the activity and abundance of soil fauna such as *Enchytraeidae* (Lagerlof *et al.*, 1989) as well as decomposition by soil microbes (Sileshi *et al.*, 2008). The presence and quality of the litter (below and above ground) increases the abundance of earthworms, as van Eekeren *et al.* (2009) showed in a comparative study of white clover (*Trifolium repens*) and ryegrass (*Lolium perenne*). Soil invertebrates, including earthworms and centipedes, were found to benefit from incorporating legume material pruned from leguminous trees into the ground in maize cropping agroforestry systems (Sileshi *et al.*, 2008) indicating that such added nutrients may benefit decomposer groups and the soil food web.

Above-ground plant structure of legumes

Legumes compete with non-crop species in a way that contrasts with monocotyledonous crops such as cereals or maize. This leads to weed communities that are different to those in monocotyledonous crops (Meiss *et al.*, 2010c). Climbing and creeping growth forms add further structural complexity, which is of particular relevance in intercropped and undersown systems that have a high leaf area index (Bilalis *et al.*, 2010). Thus, where legumes are strong competitors, such as the fast-growing and creeping white clover (*T. repens*) within green mulches, intercropping and undersowing can reduce non-crop vegetation preventing invasion of swards by otherwise competitive weeds (Frankow-Lindberg *et al.*, 2009). Legume-based cover and green manure crops may alter the community structure of associated vegetation in favour of broadleaved species leading to the maintenance of a more diverse community featuring a greater range of rare plant species (Meiss *et al.*, 2010c).

The regrowth of a perennial legume such as lucerne or clover allows several harvests/cutting cycles per year and creates longer ground cover. The cutting regime has a strong influence on floral and faunal composition and diversity (Everwand *et al.*, 2014). In grassland systems with legumes the balance between cutting and grazing can also influence the persistence of legumes within the sward. Grazing maintains legume cover more effectively than cutting (Woodcock *et al.*, 2014). The presence of perennial grass or grass–legume leys in rotation affects the weed flora (Meiss *et al.*, 2010b) and can reduce the risk of noxious annual weeds (see Chapter 11, this volume).

Root characteristics and morphology

Legume-supported systems impact on vegetation communities via changes to soil structure, seed bank and soil chemistry over the course of several cropping cycles. Many legumes have deep roots, high mycorrhization and high abundances of both symbiotic and non-symbiotic N-fixing bacteria in comparison to cereals.

Those root and rhizosphere characteristics improve soil structure (Mytton *et al.*, 1993; Lupwayi and Kennedy, 2007). However, root characteristics differ between legume species. The taproot of faba bean (*V. faba*) for instance is larger and more robust than that of other cool-season legumes (see Chapter 5, this volume). The roots of lucerne can grow deeper than 2 m, and transport assimilates down as well as nutrients up through the soil profile (see Chapter 11, this volume). Additionally, lucerne roots release allelopathic compounds, some of which directly limit the growth of weed flora in the later stages of a crop rotation (Xuan and Tsuzuki, 2002) or suppress root damage by pathogenic nematodes and enhance interspecific biocontrol within the nematofauna, as shown for the legume species *Mucuna pruriens* var. *utilis* (Blanchart *et al.*, 2006). This reduces the need for pesticide input and weed control measures. For example, lucerne is used as a 'biological break' in a rotation to reduce soil pest populations that may build up over successive seasons of other arable crops (Altieri, 1999).

How Management of Legume-supported Cropping Affects Biodiversity

Crops are managed to maximize production and control competitive weeds, pests and diseases. When considering management effects, it is useful to differentiate between beneficial and detrimental organisms. Pollinators or predators are welcomed by farmers, but they are often affected by management that is targeted at pests and weeds. While this is a common problem with most crops, management of legume systems affect diversity in ways that differ from the effects on other crops.

Weed control – management of non-crop flora

In conventional crops, many non-crop flora species are considered to be 'weeds'. However, many of these weeds may not have detrimental effects on the crop and even provide benefits for agrobiodiversity (Albrecht, 2003). Regardless, the increased control of weeds is responsible for significant declines in flowering plant species, including those once common in agricultural habitats and in any intensively managed crop, herbicide use and tillage practices reduce non-crop vegetation biodiversity (Hole *et al.*, 2005; Swanton *et al.*, 2006). Some legume crops, such as lupins, are very susceptible to post-emergence herbicide application, so to avoid this cultural control methods such as harrowing are used on such legume crops (see Chapter 6, this volume).

Several legume crop species are competitive and suppress non-crop vegetation. However, not all legumes (e.g. peas) are sufficiently vigorous to significantly reduce weed abundance via competition when grown as a single crop (Deveikyte *et al.*, 2009). Reduced weed pressure can also be achieved by deliberate choice of site-specific crops, crop mixtures or rotations, for example by alternating perennial and annual crops (Meiss *et al.*, 2010b) or by intercropping legumes with cereals to increase the competitiveness of the crop mixture and to reduce the need for herbicides (Hauggaard-Nielsen *et al.*, 2001; Poggio, 2005). In organic systems

in particular, white clover–ryegrass leys are included in rotations specifically for the purpose of growing highly nutritious feed for animals, increasing soil fertility and for controlling annual weeds (Hole *et al.*, 2005). The length of the perennial ley is also an important factor influencing weed dynamics due to a balance between species competitiveness and the influence of the lack of disturbance in the ley phase: Anderson (2010) suggests 3 years of lucerne is more beneficial than longer or shorter leys. Reduced weed management can even limit weed populations in the longer term: if weeds act as a food source for seed-feeding organisms, the presence of weeds can encourage the activities of these organisms and reduce the weed seed bank (Meiss *et al.*, 2010a). This in turn can create a positive feedback on overall biodiversity, especially if no- or low-till management is implemented with intercrop mixtures. However, the effects of including legume crops in rotations on weeds vary. The diversity and abundance of certain weed species can either increase or decline, depending on system design, management practices and weed species (Murphy *et al.*, 2006; Graziani *et al.*, 2012). Overall, the impacts of weed management in individual legume-supported cropping systems will depend on how the potential vegetation community is affected, and the competitiveness of the legume versus other crop and non-crop plants. Thus, only a well-planned and well-informed legume-supported crop rotation can help to keep competitive weeds below problematic levels and achieve the target of positive effects on biodiversity.

While legume-supported cropping in Europe is predominantly concerned with herbaceous plants, many leguminous tree species are used in agricultural systems elsewhere. For example, in tropical areas with particularly nutrient-poor soils and where predominantly low-input subsistence farming is practised (Graham and Vance, 2003), material pruned from leguminous trees and hedgerows can be incorporated into the soil, resulting in yield increases of maize (Egbe *et al.*, 1998). Some leguminous tree species such as acacias have additional allelopathic properties leading to enhanced suppression of weed germination from the soil seed bank (El-Khawas and Shehata, 2005). Such use of leguminous tree species for short rotation forestry might also fit in some European systems and could be beneficial for biodiversity via diversified landscapes.

Pest control – management of crop-associated fauna

Legume traits such as high plant N, flowering and extra-floral nectaries make legumes a potential food source not only for pollinators but also for other herbivores which can potentially become pests. In addition, they provide habitat and food sources for potential pest control agents, including predatory and parasitoid insects (Géneau *et al.*, 2012). The diversity of fauna, both beneficial (pollinators and natural enemies) and detrimental (pests) in legume-supported systems, however, is heavily dependent on the type and frequency of chemical pest control as well as crop and rotation management.

Organic systems, which lack pesticides and mineral fertilizers and have different crop rotations compared with conventional ones, are often associated with increased diversity and abundance of fauna. This may be attributed to the

presence of legumes (e.g. Power and Stout, 2011). However, although many studies have demonstrated increased fauna associated with organic practices, it is difficult to determine which component of organic farming is responsible (Gabriel *et al.*, 2013). As well as legume-supported cropping, other organic and integrated management options include: (i) modifications of planting time, tilling regime and fertilizer application in relation to the pests' life cycle; (ii) intercropping to divert pests or attract natural enemies; (iii) using trap crops, natural plant products or biopesticides alone or in combination with synthetic pesticides; or (iv) the deployment of resistant varieties and other measures (Sharma *et al.*, 2005). Thus it is not simple to disentangle the effects of legume cropping from the effects of other practices in organic systems.

Other legume-supported management practices which influence crop fauna include intercropping with legumes, adding them to field margins or including them in rotations. Such practices can provide more diverse resources and habitats for a range of faunal species over both spatial (within fields, across the landscape) and temporal (over a longer period of time) scales. This can reduce pest and disease pressure due to physical barriers and larger spatio-temporal distances between host plants. Such practices can also increase structural complexity of vegetation, providing additional habitats for invertebrate species. Thus cover crops, undersowing, intercropping, legume-based field margins and mulches can increase beneficial invertebrate biodiversity (Curry, 1986; Osler *et al.*, 2000) and the ecosystem services, such as increased biocontrol, provided by it (Hooks and Johnson, 2001; Midega *et al.*, 2009).

Management of fungal disease

Fungicides used to control diseases may have negative effects on symbiotic and neutral fungal organisms and higher trophic levels. Legumes can disrupt host availability for the pathogens, but host plant resistance is the best means of disease control (Stoddard *et al.*, 2010). Furthermore, the risk of fungal infestation of the crop can be reduced (in both legume-supported and conventional cropping systems) by adjusting seed density, water and nitrogen management. Additionally, maintaining sufficient intervals between potential host plants reduce the risk of fungal diseases.

Soil management

In legume-supported cropping systems, tillage and crop rotation are often closely linked. This is because the root morphology of many legumes allows no-till farming practices on the following crop, which leaves the soil structure intact and crop residue on the field surface. This reduces soil disturbance and promotes beneficial insects and earthworms, as well as increasing microbial activity, and helps with preservation of soil organic matter. No-till management further increases the amount and variety of other wildlife due to improved cover, reduced soil compaction and the reduced chance of destroying ground-nesting birds and mammals.

Legume-supported crop rotations, such as those incorporating red clover and soybean, benefit some groups of soil fauna, including earthworms (Jordan *et al.*, 2004). Earthworm populations increase soil aggregate stability and the storage of C and N in a soybean cropping system (Ketterings *et al.*, 1997), but earthworms are affected by soil disturbance (Curry *et al.*, 2002). Impacts of legume cropping on earthworms are therefore moderated by soil management practices. For example, Schmidt *et al.* (2003) assessed the effects of the absence of tillage and the presence of a permanent white clover understorey on earthworm populations in winter wheat cropping systems. They found only a modest effect of the absence of ploughing alone, but the combination of absence of ploughing and presence of a clover understorey greatly increased earthworm populations. This suggests that large earthworm populations in legume-supported cereal cropping systems are primarily supported through the organic matter input from such systems sustaining a food supply throughout the year (Schmidt *et al.*, 2003). The abundance of earthworms is further influenced by the rate at which earthworm populations can recover after disturbance by reproduction and colonization from neighbouring undisturbed soil. For example, at least 2 years of permanent grass/clover cover are required for the full development of earthworm populations, even in highly favourable temperate soils (Schmidt and Curry, 2001). Earthworm populations in crop rotations are therefore likely to fluctuate depending on crop type and management, order of rotation and duration of non-tilled recovery periods. The potential benefit of legumes for earthworms would have to be weighed against potential negative impacts of soil disturbance through tillage.

Small-seeded, dormant and rapidly germinating ruderal plant species are able to take advantage of newly tilled soil. Legume-supported systems incorporating no-till or reduced tillage may see a reduction in the abundance of ruderal non-crop species. Additionally, legume cropping systems, with improved soil quality, may promote seed-feeding soil organisms, as well as higher microbial activity, resulting in faster rates of seed decay. This can reduce seed longevity and create 'weed-suppressive' soil conditions (Meiss *et al.*, 2010a).

Harvesting

The effect of crop residues on subsequent crops depends on the efficiency of harvesting methods and recombination of material into the soil. Increases in N-rich organic matter in soils following some legume crops may promote non-crop vegetation biodiversity. Organic matter of some legumes, such as lucerne, may suppress other plants with allelopathic compounds remaining in the soil after harvesting the crops. To protect ground-breeding birds, small mammals and amphibians while maintaining a habitat and food source for pollinators in forage legumes, it is considered best to harvest lucerne at least 8 cm above the soil surface and not more often than three times per year. This maintains a high regrowth capacity for the plants, optimal quality and profitable regrowth. Leaving strips of the forage legume near field boundaries or within the field in an alternating manner with every harvest provides additional positive effects for biodiversity. These strips could also provide habitat and flowers for pollinators, even if most of the field is cut three times a year (DAFA, 2012).

Legume-supported Cropping Affects Biodiversity at Site and Landscape Scale

Increasing the diversity of crops creates a greater range of habitats and a more heterogeneous landscape, which can increase niche and thus species diversity (Kleijn and Verbeek, 2000; Tschardt et al., 2005). Therefore, adding legumes to the cropping system in regions dominated by cereals (Altieri, 1999) leads to greater spatial and temporal habitat diversity. With a more complex landscape (e.g. with more boundaries between habitat types), biodiversity (including habitat diversity, as well as the abundance and richness of pest and beneficial arthropods) may be enhanced (Duelli, 1997). When legumes are added to crop margins or as cover crops, food resources are provided for beneficial organisms, especially in comparison to where margins or fields are left bare and resources are scarce.

To sustain a diverse community of pollinators in landscapes otherwise dominated by grass and cereals, it is crucial that nectar- and pollen-providing legumes and other plants, including crops, flower (Woodcock et al., 2014) and that pollinators and higher trophic guilds are not affected by non-selective systemic insecticides (Goulson et al., 2015). Furthermore, although they provide a substantial resource for pollinators, legume crops, like most mass-flowering crops, flower for only a short time. Perennial legumes, such as lucerne, have longer flowering periods, so they provide a food source for a wider range of pollinators, especially when other mass-flowering crops such as rapeseed have stopped flowering (Knight et al., 2009; Stanley et al., 2013).

Pollinator responses to legumes in field margins and to different crops depend on the surrounding landscape context and crop management regimes (Knight et al., 2009; Stanley et al., 2013). Different crops or wild flowers attract different pollinators (Rollin et al., 2013; Garratt et al., 2014; Grass et al., 2016), and so planting field-margin floral resources has a bigger effect in arable crops than in forages and in simple rather than complex landscape contexts (Scheper et al., 2013). A landscape with a wider range of crop and non-crop flowers can support a greater diversity of pollinators. As such, legumes can contribute to the landscape-wide diversity in floral resources to support pollinators.

Such changes at the landscape scale have the greatest impact on larger and more mobile organisms such as farmland birds, bats, vertebrates and flying insects through provision of increased foraging and nesting habitats, and range of food, prey or other resources (Wilson et al., 1997; Wolff et al., 2001; Santangeli and Dolman, 2011; Andersson et al., 2013). For example, lucerne crops are significant habitats for other taxa such as grasshoppers (Bretagnolle et al., 2011) and small mammals (common vole and mouse species) that overwinter and reproduce there (Inchausti et al., 2009), and are a main prey for top predators, such as raptors (e.g. Montagu's harrier, *Circus pygargus*; Salamolard et al., 2000). The abundance of these prey species drives the population dynamics of their predators at the landscape scale. An increase in the area of lucerne benefits skylarks (*Alauda arvensis*) (Kragten et al., 2008), ortolan bunting (*Emberiza hortulana*) (Morelli, 2012) or the little bustard (*Tetrax tetrax*) (Bretagnolle et al., 2011), which are birds of high conservation value.

Conclusions

Legume-supported cropping can have significant impacts on biodiversity in agroecosystems, both above and below ground, locally, on individual farms, and at the landscape scale. The relationships between legume crops and non-crop flora and fauna are highly complex, and there is no single overriding positive or negative effect on biodiversity in general.

Overall, increasing the use of legumes will generally improve biodiversity in European agricultural landscapes. Nevertheless, it is important to consider the many factors impacting negatively on biodiversity, such as rotational problems and crop protection measures. Furthermore, alternative implementation measures need to be taken into account to achieve the expectations. It is clear, however, that a more in-depth approach to comparing the biodiversity of legume-supported and conventional cropping over regional and global scales is required before biodiversity costs and benefits can be accurately quantified.

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