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Editorial

Managing agrobiodiversity: integrating field and landscape scales for biodiversity-yield synergies




Biodiversity in and across landscapes is entangled with agriculture, with farming affecting biodiversity across scales (Beckmann et al., 2019). Over thousands of years, farming practices across different landforms and soils promoted a mosaic landscape with high biodiversity, which can support the productivity of agricultural systems through ecosystem functions and services, such as pollination, pest control and soil fertility (Dainese et al., 2019). Biodiversity can also limit the productivity of agricultural systems through pest damages (Savary et al., 2019; Fig. 1). However, the positive or negative tendencies of biodiversity on agriculture depend on the choice and intensity of farming practices and their consequences for the presence and absence of species. Studies have shown that intense agricultural practices tend to reduce biodiversity, homogenize crop production, and facilitate the spread of plant diseases or pests (Beckmann et al., 2019; Cheatham et al., 2009). More specifically, some formerly abundant arable plants are now becoming increasingly rare (Hurford et al., 2020), farmland birds have declined strongly (Rigal et al., 2023), and major losses of grassland butterflies have been observed (Warren et al., 2021). Agricultural activities have drastically reduced semi-natural habitats such as field margins and hedgerows, and hence, the biodiversity associated with these spaces. The process of simplifying crop or livestock species has coincided with largely homogenized farming practices relying on many inputs such as synthetic fertilizer or pesticides (Lyon & Welsh, 1993; Nyström et al., 2019). On the other hand, agroecological practices that diversify production systems, tend to increase productivity while supporting a more diverse biological community (Tamburini et al., 2020). Therefore, diversified agro-ecosystems can contribute to ecological intensification of agriculture, which proposes the replacement of external inputs such as fertilizer or pesticides with ecosystem services (Bommarco et al., 2013, Kleijn et al., 2019). As climate change additionally threatens the existence of certain species, the food webs and ecological functions they contribute to, it will become increasingly important to disentangle the relationships between farming practices, biodiversity, and yields.

Farming and land use practices have effects beyond the boundary of the field, reaching up to the landscape scale and further (Sayer et al., 2013; Gámez-Virues et al., 2015; Kernecker et al., 2022). Therefore, considering the landscape scale is essential when thinking about biodiversity-productivity relationships (e.g. Martin et al., 2019; Raatz et al., 2019). It has been established that landscape heterogeneity benefits biodiversity (i.e. multi-trophic diversity) (Sirami et al., 2019), and that this in turn benefits agricultural yield at the field scale through pollination and pest control (Dainese et al., 2019). In practice, however, agricultural landscapes are not typically managed for heterogeneity, and attempts at increasing structural heterogeneity are slow and complex, largely due to challenges in governance (Hill et al., 2015; Leventon et al., 2019).

Furthermore, although there is evidence that diversification at the field and farm scale is a promising tool for more sustainable agricultural systems (e.g. Ponisio et al., 2015), we often lack knowledge why particular measures achieve the desired results in particular cases, but not in others (Albrecht et al., 2020). In order to understand how farming practices promote more heterogeneous agricultural landscapes that benefit species diversity across trophic levels and contribute to stable or increased production, we need to study local measures across a wide

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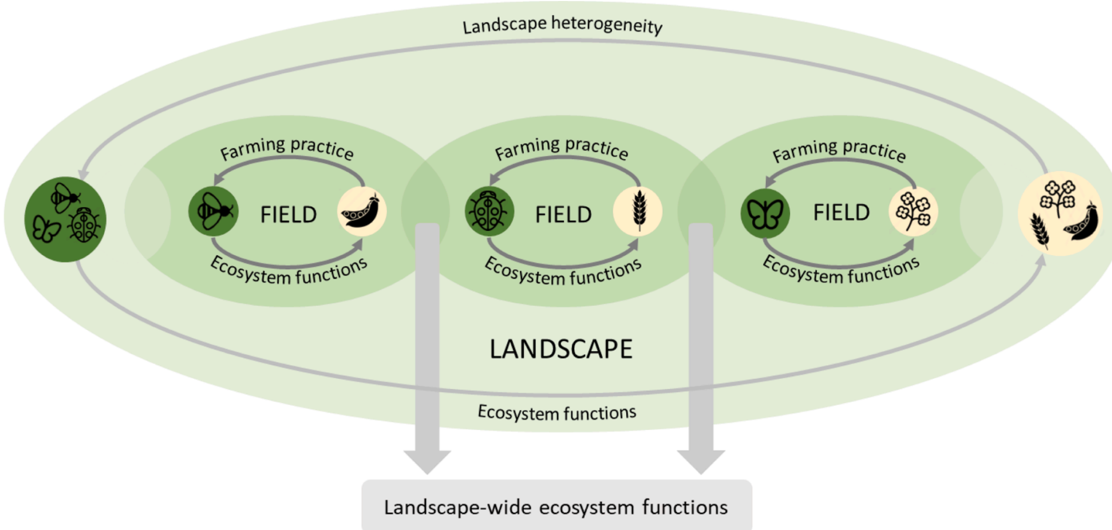

Fig. 1. Conceptual overview of how to diversify at the field scale, through crop rotations, species, or varietal mixtures for temporal effects. Here, this would mean diversifying the composition of landscape with the three fields, as seen here (mid-green ovals), with three different crops (legume, grain, oil seed, in light yellow circles). This would interact with biodiversity (bee, beetle, and butterfly icons in dark green circles) and together they would shape biodiversity and yields at the landscape scale. At the field scale, the effect of yield productivity on biodiversity depends on farming practices, and biodiversity affects agricultural yields through diverse ecosystem functions depending on the field to landscape interaction. This interaction accounts for field scale diversity and landscape heterogeneity (composition and configuration). Both can be promoted depending on the farming practice, and there may be a trade-off depending on the farming practice, but also the landscape.

range of case studies and consider how landscapes can be organized into distinct but interacting agroecosystems, thereby making use of the diversity of farming practices.

Each of the studies that compose this Special Issue addresses the general question about how farming practices and biodiversity affect the productivity and sustainability of agricultural systems. The collection of articles investigates this relationship from different angles, focusing on specific trophic groups (e.g., birds, pollinators, soil invertebrates) and farming practices (e.g., management intensity, crop composition at field scale) to explore the effects of local and landscape-wide management practices on ecosystem functioning, crop yields, and the conservation of biodiversity within agricultural landscapes. In this Special Issue, we shed light on 1) enhancing or potentially stabilizing yields through the diversification of cropping systems, including in-field crop varietal diversity, and the conservation of functionally relevant species and the ecosystem services they provide in comparison to conventional practices (Jones et al., 2023; Cissé et al., 2023; Gavín-Centol et al., 2023); 2) reducing damages to yields with different measures including the integration of rare arable plants into farming systems, increasing crop compositional heterogeneity, intercropping within fields, as well as reducing the intensity of management (Twerski et al., 2023; Priyadarshana et al., 2023; Krieger et al., 2023; Law et al., 2023); and 3) management practices for enhancing farmland biodiversity at the local scale, with implications for landscape scale management (e.g. via accounting for multitrophic spill-overs between fields or land-use systems), e.g. through pollination and bird habitat creation (Fijen et al., 2022; Zaragoza-Trello et al., 2023; Guitérrez-Briceno et al., 2023; Guerrero et al., 2024; Peréz et al., 2023). This Special Issue thus aims to contribute to a less conflicted discourse between agricultural production and biodiversity conservation by emphasizing how they are intertwined. Moreover, it showcases a wide range of case studies on farmland diversification measures which are urgently needed for practical implementation.

Diversification of farming systems at the field scale is often presumed to increase habitat availability for different species, while also enhancing functional redundancy of diverse species within the system and thereby benefiting yields. This Special Issue starts with a meta-analysis by Jones et al. (2023), which underscores the complex and context-dependent relationships between biodiversity and agricultural yield in diversified farming systems. In their study, they defined diversified farming systems as those that increase on-farm diversity with different plant species, different crop varieties, or the integration of livestock or fish with crop production. Using a dataset of field experiments that measured both biodiversity and yield responses in diversified treatments and simplified controls, they found that the context, including crop type, climate zone, diversification practice and the metric used to assess outcome, influenced the effects of farming system on species richness and evenness. Jones et al., (2023) show that farming system diversification is more likely to lead to a win-win scenario for biodiversity and yields when different diversification practices are implemented together and if there are no inputs of agrochemicals, particularly in milder climates.

Generalized findings from meta-analyses may not always mirror individual outcomes of cases or field studies which often provide more details on contextual relationships, such as biogeographical or climatic regions or farming systems. In this Special Issue, we have a wide collection of articles that provide novel insights to contextual relationships between biodiversity and agricultural yield, or the ecosystem functions that lead to yields, through a range of farming practices at different levels of diversification. Diversification can broadly be successful for win-win scenarios for both biodiversity and yields, but context is also important for understanding the management effects on biodiversity and what that means for agricultural production (Albrecht et al., 2020). This may become even more relevant in the face of climate change, due to the functional redundancy of species that is enhanced through diversified practices. As such, diversification at field, farm, and landscape scales should support farmers in dealing with undesired species, support pollination and farmland birds.

In particular, the meta-analysis findings from Jones et al. (2023) were confirmed by two individual studies, in distinct locations. First, Cissé et al. (2023) investigated the effects of phenological mixtures of pearl millet varieties in Senegal. They compared plots growing single varieties with plots growing a mixture of early- and late-flowering landraces in typical Sahelian conditions of low fertilization and limited rainfed. Cissé et al., found no effect of mixtures on dry fodder yield, but a highly significant impact on grain yield. In particular, mixture plots showed an average surplus on grain yield compared to monovarietal plots, which may be important for yield stability given the inevitability of climate change effects. A second study by Gavín-Centol et al. (2023) demonstrated how diversification of farming systems may support soil ecosystem functions. In a long-term comparative field trial of conventional and biodynamic farming systems in Switzerland, Gavín-Centol et al., 2023 found that severe drought and conventional farming practices can reduce the feeding activity of soil detritivores (collembolans and oribatids) at different soil depths. This leads to lower decomposition and nutrient cycling in soil ecosystems, which could have long-term implications for yield outcomes. These two studies demonstrate that diversification practices, such as cultivation of variety mixes or use of organic fertilizers, can buffer drought effects that may deteriorate solid functions and consequent yield outcomes.

Individual farming practices that can contribute to diversification in fields and across landscapes have variable effects on different pest species with implications for yields, as depicted by four studies in the special issue. These address how farming practices can contribute to prevent the effects of undesired agrobiodiversity, including pest aphids in cereal crops (Twerski et al., 2023), pest butterflies in vegetable crops (Priyadarshana et al., 2023), native invading plant species in temperate grasslands (Krieger et al., 2023), and weed seeds in crops (Law et al., 2023). Twerski et al. (2023) investigated the role of rare arable plants for pest control in cereal crops in Germany, finding that in both experimental and study fields, increasing plant diversity through rare arable plants did not significantly affect aphid density and predator activity (spiders and carabids). In the experimental field trial, they found effective pest control potential via a higher cover of rare arable plants and the activity densities of actively hunting spiders, both of which were associated with decreasing numbers of aphids. However, these results could not be replicated in the field study on ten farms, indicating that environmental contexts and other interacting mechanisms may moderate the effects of rare arable plants on pest control. Priyadarshana et al. (2023) demonstrated that increasing crop compositional heterogeneity reduced the abundances of a butterfly pest (*Pieris canidia*) in agricultural fields in a case study on 52 study fields in China. However, increased field margin lengths (crop configurational heterogeneity) did not reduce pest butterfly abundance. This study shows that increasing the diversity of crops and avoiding large areas of functionally similar crops (in this case *Brassica* spp.) can be more effective in reducing an individual pest species than higher amounts of non-crop habitat.

To understand how diversified management practices can improve or stabilize yields, we need to identify those measures that harness biodiversity to keep undesired species under control. Regarding individual farming practices to maintain productivity while reducing pesticides use, Krieger et al. (2023) showed that contrasting management practices namely grassland abandonment and intensive management can foster biotic invasions, here the spread of *Jacobaea aquatica* a poisonous plant in wet temperate grasslands. They came to the conclusion that moderate management practices can provide a balance between controlling the invasive plant and ensuring the multifunctionality of grasslands. The occurrence of undesired plant species can also be a major problem in crops. Law et al. (2023) studied weed seed predation in different farming systems, showing the ecological advantages of integrated cropping systems in terms of promoting beneficial invertebrates and reducing herbicide use through seed predation, without sacrificing crop yields. To make use of ecosystem services provided by biodiversity, it is important to understand the mechanisms how increased species richness leads to yield increases. This was explored by Zaragoza-Trello et al., 2023 by investigating functional complementarity of pollinators in sunflower crops. Specifically, they suggest that temporal niche complementarity plays a more significant role than spatial niche complementarity of pollinator visitation rates. Interestingly, they found unexpected outcomes in seed weight depending on pollinator activity periods and the amount of time the pollinators were exposed to sunflowers.

In addition to promoting ecosystem services and suppressing disservices, it is also necessary to increase farmland biodiversity in general, which is important for ecosystem functional stability (Balvanera et al., 2006; Senapathi et al., 2021). The intensity of individual farming practices shapes the year-round habitat suitability of species with larger activity ranges relevant for landscape scale processes. Therefore, farming practices affect plant-animal interactions at the field scale, while also having landscape scale effects. This Special Issue shows how diverse farming practices, particularly crop choice, can enhance plant-pollinator interactions that span from field to landscape scales, as demonstrated by two studies in different contexts. Fijen et al. (2022) demonstrate that honeybees play an important role in ensuring sufficient crop pollination services in buckwheat fields in the Netherlands. Simultaneously, buckwheat cultivation can also contribute to wild pollinator conservation by providing nectar resources scattered throughout the agricultural landscape during a period of nectar scarcity. This is largely because competition for resources between honeybees and wild pollinators in buckwheat fields is limited. Consequently, buckwheat crop yield depends on pollinator (honeybee and wild pollinator) density. Looking beyond specific pollinated crops, Gutiérrez-Briceno et al. (2023) found that landscape composition and agroecological practices impact wild bee communities in horticultural farms in central Spain. They demonstrated that on-farm agroecological practices, like weed control, natural fertilizer usage, pest control, crop diversification, and the presence of specific habitats (sparse vegetation, forested areas, pasture), enhance wild bee species richness and abundance. Their study implies that diversified small-scale horticulture can benefit pollinators through the provisioning of additional habitats in the agricultural landscapes. Thus, diversified cropping practices allow for niche complementarity for diverse species at landscape level, in particular benefitting wild bee species (Beyer et al., 2021; Schweiger et al., 2022).

Furthermore, two studies in this Special Issue deal with understanding the interactions of birds with agricultural systems. Focusing on the functional diversity of bird communities, Guerrero et al. (2024) found that in-field agricultural intensification affects the community assembly of bird communities filtering for shorter-lived communities and more generalists while farmland-adapted species are declining. These functional shifts in bird communities may have consequences for the provisioning of ecosystem services as typically farmland-associated species provide important ecosystem services, such as biological control (Marcacci et al., 2021). Likewise, Peréz et al. (2023) studied bird communities in olive groves in Spain, and found that the management intensity of olive groves affects wintering bird communities, with the presence of olive fruits promoting frugivore abundance. In addition, Pérez et al. (2023) identified that traditional and intensive management of olive groves can sustain large numbers of wintering birds but that intensive management tends to reduce species richness, particularly among frugivorous species. Granivorous species were strongly related to ground cover and vegetation diversity, whereas frugivorous species were related to the amount of olives on the trees. Similar to the case of pollinators, this points to the importance of niche complementarity across the landscape for different functional groups of species. Therefore, diversifying crops in order to promote species complementarity at the landscape scale is critical to support pollination services and pest control.

Lessons learned and ways forward

This Special Issue has addressed many different types of farming practices that go beyond the conventional-organic or simple-diversified dichotomies, highlighting how they benefit different species or communities. The studies show compelling evidence that various diversification measures and less intensive management practices can enhance yield through increased ecosystem service provision (Jones et al., 2023; Cissé et al., 2023; Gavín-Centol et al., 2023) or through decreased disservices, e.g. by reduced pest abundances (Twerski et al., 2023; Priyadarshana et al., 2023; Krieger et al., 2023; Law et al., 2023). Moreover, these measures can contribute to farmland biodiversity conservation (Fijen et al., 2022; Guitérrez-Briceno et al., 2023; Guerrero et al., 2024; Peréz et al., 2023). Mobile species can benefit from functionally diverse landscapes, making use of different habitats at different temporal scales (Guitérrez-Briceno et al., 2023; Zaragoza-Trello et al., 2023; Peréz et al., 2023). Landscapes can become more diverse by making use of the manifold practices described here in this Special Issue, especially if they are diversified in space and in time. In addition, incorporating the multiple landscape scale interactions is key to upscale and generalize biodiversity-yield patterns (Fig. 1). This includes considering boundary characteristics, connectivity at the landscape scale, and spill-over effects of farming practices and biodiversity effects on yield.

Despite the major advances that the articles in this Special Issue contribute to, there is still a long way to go to systematically adopt biodiversity-friendly farming practices at the landscape scale. One way to address this issue is by promoting agri-environmental policies and governance arrangements that foster spatio-temporal coordination and cooperation between farmers for landscape scale management (Pe'er et al., 2022; Petit & Landis, 2023). However, few studies have investigated farmers' willingness and drawbacks to implement biodiversity-friendly farming practices coordinated at landscape scale (Alblas & van Zeben, 2023). The three papers of this Special Issue investigating plant-pollinator interactions (Fijen et al., 2022; Zaragoza-Trello et al., 2023; Gutiérrez-Briceno et al., 2023) point to this solution, but further research is necessary to investigate their effectiveness to promote biodiversity and ecosystem services in agricultural landscapes.

Furthermore, climate change interacts with agricultural practices at all scales, causing range shifts and phenological changes. In this Special Issue, Cissé et al., (2023) demonstrated that phenological mixtures of crop varieties can provide some stability in the face of weather extremes, and Gavín-Centol et al. (2023) showed that less input-intensive management may partly buffer negative drought effects, but this still needs to be further explored in the future. This is particularly key in combination with the different range of farming practices, from intensive to extensive management and habitat mixtures. As diverse farming practices are increasingly implemented across landscapes, agriculture and biodiversity will co-evolve by forming new functional relationships that will change into unknown directions as novel ecosystems and landscapes emerge with climate change. This will make functional diversity of farming practices, species across trophic levels, and selected land uses increasingly important to facilitate agricultural production while supporting biodiversity.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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