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RESEARCH ARTICLE

Diversification for sustainable and resilient agricultural landscape systems

Moritz Reckling[1,2] · **Christine A. Watson**[2,3] · **Anthony Whitbread**[4] · **Katharina Helming**[1,5]

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Abstract

This virtual issue comprises papers that address diversification for providing sustainable solutions at different scales from cropping and grassland to food systems. The authors investigated processes in case studies at the landscape scale where synergies and trade-offs between social and environmental objectives become the most tangible. Contributions from all continents highlighted regional specificities related to diversification and include research from natural and social sciences, with inter- and transdisciplinary approaches including synthesis of knowledge (reviews), empirical studies with experiments as well as assessments with interviews in case studies: Model-based design of crop diversification, the role of digitalization for achieving sustainability in the European context, ecological engineering for rice pest suppression in China, the role of cereal species mixtures in Ethiopian smallholder farmers, diversified planting in arid irrigation areas in northwestern China, integration of legumes in European and Canadian cropping systems, screening of native forage legumes for northern Swedish grassland systems, cropping system diversification of smallholder farmers in south-central Bangladesh, identification of how farmers imagine diversified landscapes in southern Idaho in the US, farm diversification affecting impacts from COVID-19 across Europe, the role of diversified farming in Mato Grosso Brazil, diversification and soil management measures in Germany, value chain formation for the scaling of crop diversification, and the design process with farmers and scientists for the transition toward legume-supported farming in Europe. A key finding from these examples is that agricultural intensification has led to the simplification of cropping systems and landscapes in terms of species diversity and ecosystem function. To instead move towards sustainable transformation, all system levels (i.e. from the plot, farm, landscape, governance and overall food systems) need to interact and reinforce each other for diversification to deliver the desired outcomes.

Keywords Co-design · Crop-livestock systems · Food system · Legumes · Transformation

Editorial

In agricultural landscapes, spatial, temporal, and genetic diversifications of agricultural production systems are assumed to support greater ecosystem functioning, services, and biodiversity and thereby support the sustainability agenda (Beillouin et al. 2021). Diversification can reduce the dependency on synthetic inputs, lower the associated environmental impacts, and increase the resilience of crop production (Kremen et al. 2012; Tamburini et al. 2020) and of farming systems (Paas et al. 2021) as part of a transition to more sustainable agrifood systems (Messéan et al. 2021).

While a consistent framework and definition of diversification are lacking (Hufnagel et al. 2020), research on diversification is increasing (Alletto et al. 2022), and with these, documentation of the on-farm experiences with diversification (Reckling and Grosse 2022; Toffolini and Jeuffroy 2022). Diversification is understood to have agro-ecological,

✉ Moritz Reckling
moritz.reckling@zalf.de

1 Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany

2 Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden

3 Department of Rural Land Use, Scotland's Rural College (SRUC), Aberdeen, UK

4 International Livestock Research Institute (ILRI), Dar es Salaam, Tanzania

5 Faculty of Landscape Management and Nature Conservation, University for Sustainable Development (HNEE), Eberswalde, Germany

technological, environmental, organizational, governance, marketing and trade elements, and impacts. Promising approaches to diversification (Figure 1) include the following: (i) established and novel field arrangements, e.g., diverse rotations (Bowles et al. 2020), integration of legumes (Reckling et al. 2016), cover crops (Lamichhane and Alletto 2022), intercropping (Jensen et al. 2020), patch cropping (Donat et al. 2022), pixel cropping (Ditzler et al. 2021), and agroforestry (Teixeira et al. 2022); (ii) diversified farming systems, e.g., mixed crop-livestock (Ryschawy et al. 2012) and mixed livestock farming (Schanz et al. 2023), alternative social models, e.g., community supported agriculture (Vicente-Vicente et al. 2023), and care farming (Leck et al. 2014); (iii) diversified landscape systems such as rewetting of drained landscapes (Günther et al. 2020), and introduction of semi-natural habitats (Holland et al. 2017); and (iv) diversified value chains (Antier et al. 2022).

Diversified systems aim to reduce trade-offs between high productivity and sustainable use of external resources especially by reducing pesticide use (Jacquet et al. 2022), improving soil health (Zhang et al. 2020), and the provisioning of ecosystem services (Tamburini et al. 2020), including social and cultural values. Diversification is also applied to improve economic and livelihood resilience against external shocks (Meuwissen et al. 2019) and climate risk especially under low-input traditional farming systems (Nelson et al. 2022).

This virtual issue comprises papers that address diversification for providing sustainable solutions at different scales from cropping and grassland to food systems. The authors investigated processes in case studies at the landscape scale where synergies and trade-offs between social and environmental objectives become the most tangible. Contributions include research from the natural and social sciences, with inter- and transdisciplinary approaches including synthesis of knowledge (reviews), empirical studies with experiments, and assessments with interviews in case studies:

Hernández-Ochoa et al. (2022) review the model-based design of crop diversification and find that it is necessary to improve the representation of crop interactions, the inclusion of more crops, soil legacy effects, and biodiversity to assess new field arrangements. MacPherson et al. (2022) review the role of digitalization and identify options for achieving sustainability goals in future scenarios for agricultural systems in the German and European contexts. Zhu et al. (2022) review the research on ecological engineering for rice pest suppression in China, characterize the adoption including many practical examples and highlight priorities for future research. McAlvay et al. (2022) review ethnohistorical, agronomic, and ecological literature on maslins (cereal species mixtures) in two case studies from Ethiopian smallholder farmers and identify these systems as an agroecological intensification and climate adaptation strategy.

Gou et al. (2022) identify diversified planting in arid irrigation areas to improve the sustainability of cropping systems using experiments in northwestern China. Reckling et al. (2022) analyze long-term field experiments from Sweden, Scotland, and France and find that diversification with

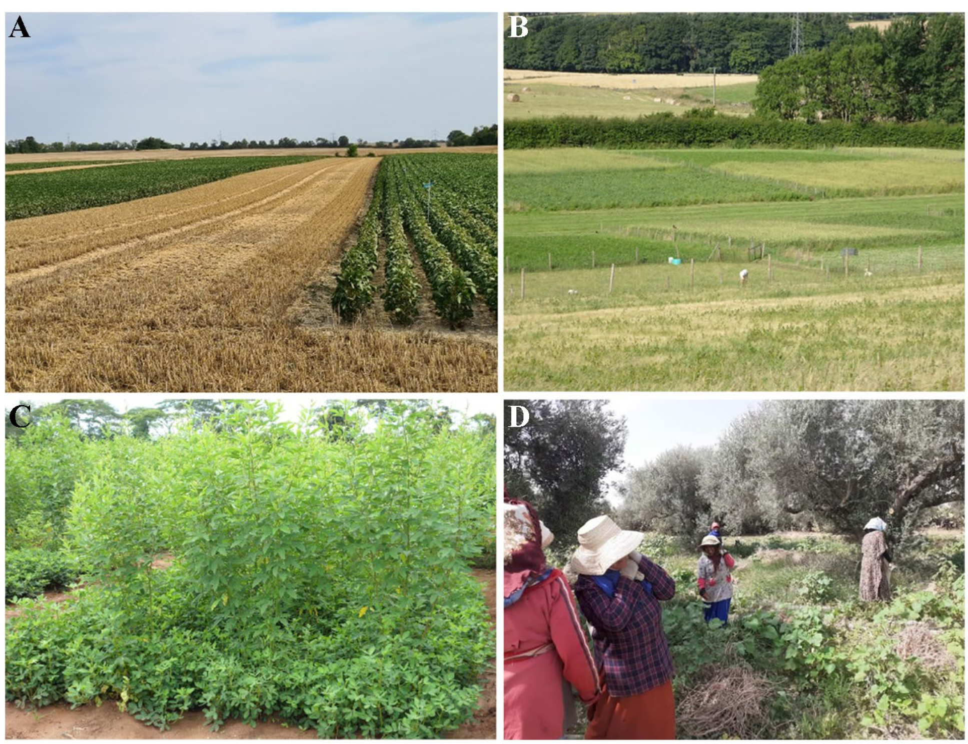

Figure 1 Diversification through soybean-wheat strip cropping in Germany (**A**) (photo credit M. Reckling), crop-livestock systems in Scotland (**B**) (photo credit C. Watson), doubled-up legumes with pigeon pea and groundnut in Malawi (**C**) (photo credit A. Whitbread), olive-water melon agroforestry systems in Tunisia (**D**) (photo credit F. Rezgui).

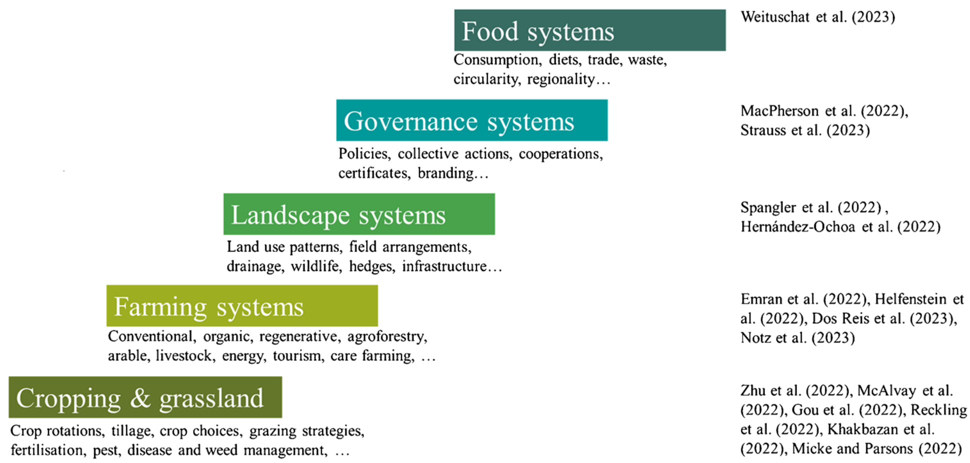

Figure 2 Agricultural diversification at different system levels. Contributions to the virtual issue include reviews, empirical studies and assessments from natural and social sciences.

legumes improves the performance of cereals in European cropping systems. Khakbazan et al. (2022) assess diverse crop rotations with pulses for improving the systems' economic profitability providing evidence from two 4-year cycles of rotation experiments in Canada. Micke and Parsons (2022) screen wild and native forage legumes using herbarium records for inclusion in northern Swedish grassland agricultural systems.

Emran et al. (2022) apply multi-criteria analysis to assess the impact of cropping system diversification on productivity and resource use efficiency of smallholder farmers in south-central Bangladesh. Spangler et al. (2022) identify what farmers are doing to manage crop diversity (the present) and how they imagine alternative landscapes (the imaginary) using interviews focused on the Idaho's Magic Valley of southern Idaho in the USA. Helfenstein et al. (2022) find specialized and intensive farms to be more likely to perceive negative impacts from COVID-19 compared to more diverse farms using farmer surveys in 15 case studies across Europe. Dos Reis et al. (2023) develop fuzzy logic indicators for the assessment of farming sustainability strategies in a tropical agricultural frontier applying it to assess the performance of diversified farming systems in the state of Mato Grosso, Brazil. Strauss et al. (2023) identify diversification as a key element in the most important sustainable soil management measures as assessed through stakeholder recommendations in Germany. Weituschat et al. (2023) explore the role of value chain formation in the scaling of crop diversification using an abductive research strategy with case studies in the north of Italy and the Netherlands. Notz et al. (2023) describe a design process with scientists and advisors in 17 case studies in nine European countries and identify trade-offs and synergies for the transition toward legume-supported farming.

The virtual issue was initiated at the "Landscape 2021" conference with the theme "Diversity for Sustainable and Resilient Agriculture." The conference was organized by the Leibniz Centre for Agricultural Landscape Research (ZALF) and attracted more than 400 participants from 42 countries. Across scales and system levels, from cropping systems to farming, landscape, governance, and food systems, diversification strategies were presented and their impact on ecosystem services and resource efficiency analyzed (Figure 2). Contributions from all continents highlighted regional specificities. A key finding emerged that all system levels need to interact and reinforce each other for diversification to be tangible and actually deliver a cornerstone toward sustainable transformation.

We conclude that a key consequence of (past) agricultural intensification has led to simplifications of cropping systems and landscapes. There is substantial evidence that diversification has the potential to improve both the agronomic and economic resilience of farming systems as well as the environmental resilience of landscapes. Current policies, e.g., the European Common Agricultural Policy (CAP), support the diversification of crop production to a limited extent but do not yet support the resilience of farming systems. A concerted effort to redesign agricultural landscapes is required to halt the loss of biodiversity and to improve delivery of ecosystem services. Promising diversification solutions are subject to local geophysical, agronomic, and socio-economic contexts, and that is why there is a high variation in both approaches to and effects of diversification across studies. Despite this diversity we see "a window of opportunity" for diversification because in the face of climate change and other crises, farmers are ready for change, even at the cost of (short-term) profit loss. New management tools and digitalization may support the transformation toward diversified, sustainable agricultural systems across scales, but traditional knowledge on the local context seems equally important. Consumption changes, e.g., toward more plant-protein-based diets can trigger production changes toward diversification providing a push-pull effect. An integrated view can be the guiding principle for improving agricultural diversification considering ecological, social, and economic perspectives. This issue adds evidence for making diversification an important step toward the transformation of more sustainable and resilient agriculture. Action at all levels is needed, i.e., crop and grassland, farming, landscape governance, food systems, and across scales to utilize this potential.

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Code availability Not applicable

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication Not applicable

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