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Exploring the position of farmers within the European green transition: transformation for whom?

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Food systems have been framed as a "wicked problem" due to the complex socio-ecological impacts they foster, ranging from contributing nearly a quarter of anthropogenic greenhouse gas emissions to a myriad of social impacts (e.g., health, food safety, and food security). In the European green transition for food systems, multiple actors are involved. However, farmers play a unique and critical role as agricultural land managers and navigators of social, political, and environmental factors. Using cover cropping and intercropping as examples, we illustrate the complexities arising when decision-making and governance at multiple levels lead to tradeoffs and unexpected consequences at the farm scale. Amid complexity, we propose a conceptual model to address the question: how is an agricultural green transition best fostered? We find that changes are incremental, transformative or both depending on the level of analysis. Additionally, incoherence in agronomic recommendations across academic disciplines and policy agendas creates challenges at the farm scale that trickle up and can thwart sustainable agricultural land use. Although transdisciplinarity and knowledge production with farmers through co-creation are essential for food system transformation and can be part of the solution, it is crucial to examine the nature of change processes and to consider how knowledge and innovation are adopted. By balancing top-down and bottom-up approaches and distributing burden from the farm scale to governance and food systems, a more transformative green transition for European food systems with coherence across multiple agroecological objectives could be achieved.

KEYWORDS

food system transformation, agricultural transition, sustainable farm systems, agricultural governance, transdisciplinary action research

1 Introduction

The unintended negative impacts of current food systems on people and the environment have been framed as a wicked problem (Rittel and Webber, 1973). Although much scientific literature and new policies have focused on transitioning toward sustainable agriculture as part of the European Green Deal (Peeters et al., 2020), how to foster a green transition continues to be contested and contextual (Boix-Fayos and de Vente, 2023). Some of the contestations arise from the broad range of approaches to sustainability transitions stemming from different disciplines and perspectives (Loorbach et al., 2017). Disciplinary differences can, to some

extent, be addressed through transdisciplinary initiatives with frameworks for governance that include non-scientific actors to create horizontal co-innovation (Fernández González et al., 2021). However, in practice, agricultural governance includes varying degrees of diverse farmer engagement and empowerment in decision-making processes (Boix-Fayos and de Vente, 2023; Loorbach et al., 2017).

Farmers have been acknowledged as critical actors within agroecological transitions, they should not be seen as a homogeneous group but as a system of actors making decisions based on a diverse range of factors (Lacombe et al., 2018; Weituschat et al., 2022). This acknowledgment has inspired micro-AKIS and other co-innovation processes that include farmers, their networks, and other place-based factors as key components of transition processes (Lacombe et al., 2018; Sutherland and Labarthe, 2022). Despite the growing body of knowledge supporting participatory innovation models and co-concepts (e.g., co-production, co-design, co-learning), many conventional governance systems continue to pass the burden of transformative change mainly to farmers and their farm systems.

In this article, we first position ourselves within existing scholarship on the agricultural green transition. Second, we propose a conceptual model. Third, we use the conceptual model to explore two illustrative examples of a conventional scenario (cover cropping) and an exploratory scenario (intercropping) to highlight the implications for transition. Finally, we return to our initial research question and discuss how an agricultural green transition is best fostered.

2 Agricultural green transition

Transition is understood as both a concept and a process; reused knowledge is in a position of power, and ideally, actors should be able to leverage novel and established knowledge to make changes (Carlile, 2004). In this context, practical and political challenges should be recognized to explain innovation adoption (Carlile, 2004). The European agricultural green transition is similarly shaped by multiple actors and challenges. Power dynamics with governance systems as part of a socio-technical regime (e.g., policy, science, industry) shape the overarching goals, methods, and practical actions farmers are required to take (Geels, 2011). Conversely, participatory research and co-concepts have gained much political traction as effective means to enable transformative change (Hakkarainen et al., 2022). For example, designing agroecological farming systems with farmers by sharing project leadership provided a useful bridge between theory and practice (Lacombe et al., 2018). It enables farm system transformation by accounting for the diversity of farmers' situations and their local food systems (Lacombe et al., 2018). However, systemic and policy factors that create power dynamics, feedback loops and trade-offs influence farmer decision-making and have significant implications for the agricultural green transition (Gemtou et al., 2024).

When considering a green transition in Europe, although we acknowledge the plethora of actors, we find a simple conceptual model focused on burden and benefit distribution useful to understand why initiatives are not providing the transformative changes intended in the field of agriculture (Figure 1). The conceptual model for transitions in agriculture describes three scenarios (conventional, exploratory, and aspirational) across three broadly conceived organizational levels critical for transition: governance, food, and farm system for burdens, and society, food, and farm system for benefits.

The organizational levels would ideally distribute the burden and benefits of transition equally to enable a holistic transformation toward sustainability (aspirational scenarios). However, drawing on illustrative examples in Denmark, there are imbalances in burden and benefit distribution. In the conventional scenario (e.g., Denmark's cover cropping policies), burdens are concentrated at the farm system level, and benefits are concentrated at both societal and food system levels (e.g., environmental risk reduction and average percent of food cost to farmers compared to other actors in the supply chain). In a transition context, it is also important to understand the impacts of scenarios that are under exploration (proposed, not adopted). In the exploratory scenario burdens are concentrated at the governance level (e.g., intercropping), and benefits are concentrated at the societal level (e.g., farmers paying for carbon emissions). In many cases, farm system benefits are uncertain at best. To better contextualize this model, we will explore the present lack of equal burden distribution in conventional and exploratory scenarios and reiterate that burden balancing will require an intentional and collaborative effort.

3 Science meets policy meets farmer: two illustrative examples

Many agricultural practices are identified as potentially supporting an agricultural green transition (Wezel et al., 2014). Practices can be categorized into two main groups: those that entail increases in efficiency or substitutive practices and those that require some degree of redesign on a cropping systems or landscape level. For this exercise, we chose to select practices that require redesign, as they generally imply more complex interactions between sectors and systems. Among the redesign practices, cover cropping and changes in crop spatial distributions via intercropping have similarities we deemed advantageous in our context and are at different implementation stages from a policy perspective. Agronomically, the two practices have similarities in that implementing cover cropping or intercropping does not require specialized equipment or technology (although it can leverage them if available). While both practices may impact crop yields, the impacts are not of a magnitude that renders the practice either overly attractive or completely untenable to producers (Li et al., 2023; Marcillo and Miguez, 2017). Furthermore, the benefits of both practices are most significant and reliable at the societal level, with potential benefits at the farm level being possible, but to a lesser degree and with less certainty (Figure 1). This similarity in societal and farm-level benefit distribution, coupled with the distinct policy phases of cover cropping (advanced) and intercropping (nascent), rendered them ideal for exploring how burdens have been distributed in a conventional policy intervention, as well as how they are evolving in an exploratory phase of policy intervention.

In the European Union, Denmark implemented some of the earliest policies relating to cover crops stemming from the 1991 Nitrates Directive (Kathage et al., 2022) and has active research related to intercropping (e.g., Aare et al., 2021). We, therefore, chose to rely heavily on literature describing the current contexts of cover cropping and intercropping in Denmark. Denmark has historically exhibited some of the most comprehensive policy interventions related to agricultural production in the European Union (e.g., Andersen et al.,

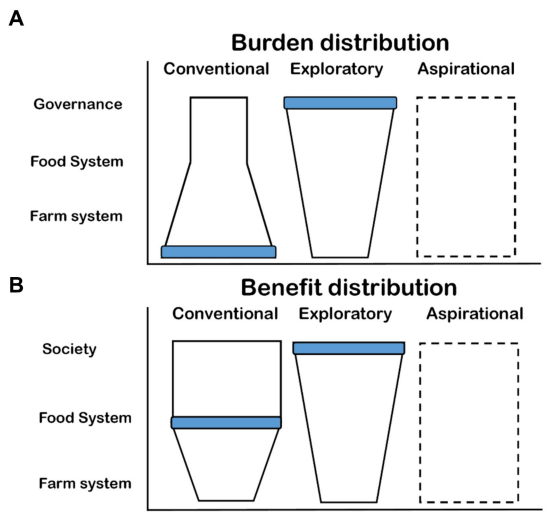

FIGURE 1
(A) Burden distribution and **(B)** benefit distribution conceptual models with three scenarios (conventional, exploratory, and aspirational) for an agricultural green transition with shapes representing burden or benefits across levels (narrow is less burden/benefit, wide is greater burden/benefit).

2017; Böcker and Finger, 2016), providing a richly documented and favorable context for comparison.

3.1 Conventional scenario: cover cropping

Annual cropping systems often result in periods where the soil is fallow, meaning there is no actively growing crop. In numerous temperate agricultural production systems, the fallow period exacerbates the risk of nutrients leaching from the soil, thereby polluting groundwater and surface water bodies (David et al., 2010; Withers et al., 2014). Cover crops (also known as catch crops) may be grown during these fallow periods to increase nutrient retention in the agroecosystem while concomitantly reducing nutrient pollution and are a common practice associated with green transition efforts (Boix-Fayos and de Vente, 2023; Figure 2). Recognizing the societal benefits that can be reaped from the use of cover crops in Denmark, a suite of policies has been incrementally enacted since 1985 that includes several regulations requiring actively growing plants in the autumn through the use of autumn-planted crops and cover crops (Dalgaard et al., 2014). When designed, the regulations had a singular focus on reducing nitrate leaching from agricultural land in Denmark, which influenced its implementation. These singular focus-driven policies have had transformational impacts on farm system planning and have unintentionally forced farmers to juggle contradicting best practices from various disciplines. For example, the policies have contributed to an increase in autumn-planted crops, which have been linked to the development of herbicide resistance in problematic weeds (Colbach and Dürr, 2003; Moss, 2017). The best management practices proposed to address this issue (e.g., delayed planting of winter crops) directly contradict practices encouraged by the cover crop policies (early planting of winter crops; Dalgaard et al., 2014). In Denmark, cover crops from the *Brassicaceae* family are effective at reducing nitrate leaching (Kumar et al., 2023). They are therefore favored by regulations, but can lead to disease carry-over into cash crops (e.g., *Brassica napus*). The policies focus on reducing excess nitrogen has also limited the use of leguminous cover crops and their attendant benefits (Allam et al., 2023; Snapp et al., 2005).

To maximize the probability of nitrate retention, requirements for timings of cover crop establishment have become increasingly calendar-based despite the increase in weather variability (Madsen et al., 2009). The timing requirements have also resulted in additional fieldwork during periods of the growing season that are both crucial to farmer's economic viability (e.g., crop harvest) and are subject to variable weather conditions. These small windows of high activity force farmers to make complicated decisions regarding trade-offs between following regulations when they may or may not be granted a weather exemption, incurring fines or other sanctions, harvesting their crops in a timely manner, and potential long-term soil compaction issues stemming from fieldwork on wet soils (Nawaz et al., 2013). Furthermore, the policies are updated and released on an annual basis, adding to the uncertainty farmers already face (e.g., weather, markets, labor availability) and making long-term crop rotation planning difficult. While the well-intended regulations have been part of a successful campaign in reducing nitrogen pollution on a national scale in Denmark (Kronvang et al., 2008), the narrow focus on nutrient management may have come at the expense of increased pesticide use (Guinet et al., 2023; Gunasinghe et al., 2020), loss of long-term soil fertility (Büchi et al., 2018), and reduced freedom for farmers to respond to situations in the most sustainable manner (Iversen et al., 2024). As a result, one could argue that the farm system has incurred the majority of the burden in this example.

3.2 Exploratory scenario: intercropping

Legume-cereal intercropping is a reemerging practice in the European green transition that includes growing two or more crops simultaneously in the same field. Although methods and species combinations vary widely, this practice, especially when implemented as a legume-cereal intercrop, has the potential to reduce environmental harm through the reduction of inputs (e.g., synthetic fertilizers) while maintaining stable yields and providing plant-based proteins for people and livestock (Glaze-Corcoran et al., 2020; Jensen et al., 2020; Maitra et al., 2021). Legume-cereal intercropping is not yet widely included in policy support schemes, but exploratory studies have looked at potential forms of policy support and necessary changes to the food system. These studies have suggested that changes needed to implement intercropping at the farm scale are minor compared to the transformations necessary at the food system and governance levels (Figure 2). For example, a wide range of actors participating in focus groups in Denmark and other European countries identified strategies to enable intercropping that primarily involved transformations in governance and food systems to be more flexible and diverse through system-oriented research and support schemes (Stone et al., 2024; Stone and Thorsøe, 2024, under review). A study in Denmark found similar results that for intercropping, farm-level issues (e.g., technical challenges, lack of knowledge) were less important than issues beyond the farm gate (Aare et al., 2021). Another Danish study highlights the host of actions needed by a variety of actors, in addition to farmers, to increase the use of species mixtures in Europe, including crop advisors, food system logistic managers, food ingredient producers, millers, machinery advisors and cooperative directors (Hauggaard-Nielsen et al., 2021). To enable widespread intercropped grains within food markets in Europe, a system for sorting or incorporating blended legume-cereal products or for providing the tested varieties and value chains necessary would require significant

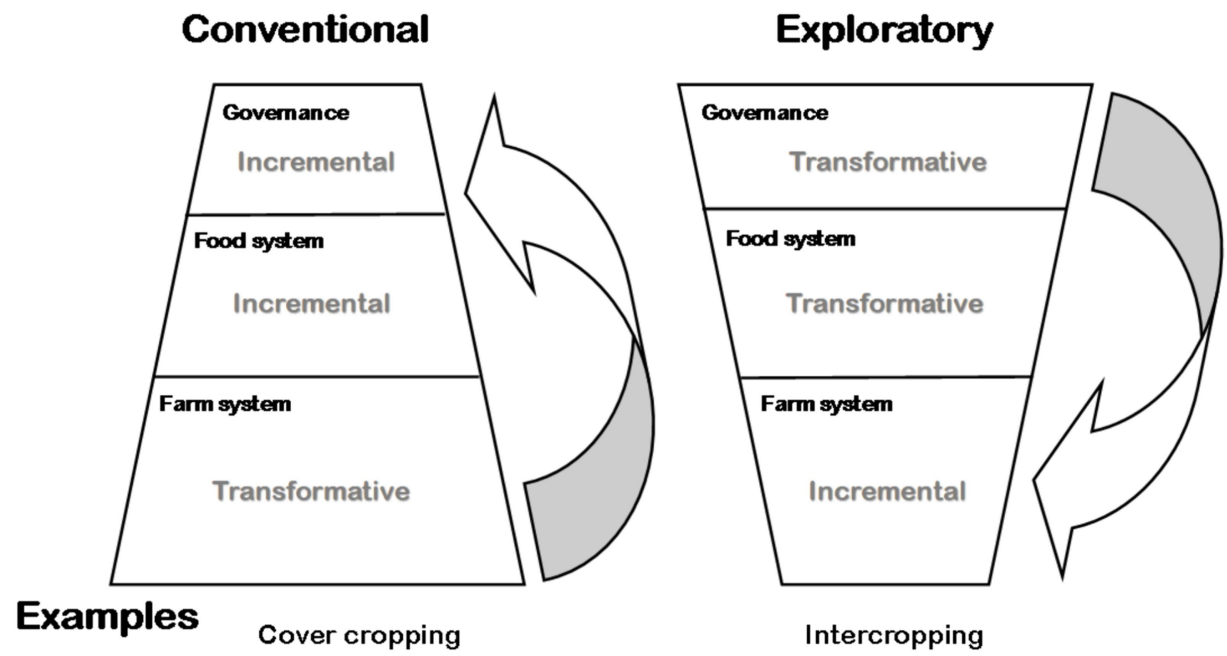

FIGURE 2
A conventional and exploratory burden scenario for a green transition in Europe with changes characterized as incremental or transformative at three levels (farm system, food system, and governance). With narrower sections representing less burden and the arrows representing re-distribution toward a more equal burden distribution.

buy-in and a series of transformations beyond the farm gate. Conversely, at the farm scale, intercropping can be incorporated into large and small, organic and conventional farming systems using similar equipment and methods already in use, and the required operations have less dramatic impacts on day-to-day operations and planning compared to cover cropping. Thus, in this example, the burden is concentrated at the governance and food system levels rather than at the farm level, as in the cover crop example.

4 Discussion: how is an agricultural green transition best fostered?

The illustrative examples exemplify that on-farm experimentation is not likely to produce a successful green transition unless integrated into a more comprehensive governance framework and value chain that aligns with and provides coherent support for new farming system models. Based on our model we propose that depending on the approach, transitions can be both incremental and transformational. Transition with increased burden distribution across levels, balancing influence from the top down and bottom up, could support more holistically transformative knowledge and innovation adoption in the context of the agricultural green transition in Europe.

The conventional and exploratory scenarios lack balance between top-down and bottom-up approaches and represent a lack of burden distribution across organization levels in European agriculture. Multi-level perspective transition models have addressed their potential bottom-up bias by developing transition pathways that offer different change scenarios balancing agency (e.g., farmer decision-making) and structure (e.g., governance; Geels, 2011). Geels et al. (2017) additionally emphasized the importance of alignment across niche, regime and landscape levels to support socio-technical transitions and provided a useful holistic framework for assessing niche momentum with innovation potential and the potential lock-ins based on regime tensions. In the context of low-carbon transitions, current regime stability and active resistance to changes by incumbent actors using politics and power were important to understanding systemic changes (Geels, 2014). Similar dynamics are essential to acknowledge and design for when considering an agricultural green transition.

Other models focus on farmer agency and highlight "good farmer" mindsets or inner dimensions that shape trajectories for sustainable farm system changes (Bakker et al., 2023; Guerra and Syed, 2024; Burton, 2004; Burton et al., 2020). Although our goal was to illustrate the position of farmers in transition, we found that governance and food system structures can limit agency at the farm system level, impacting some farmers more than others. Further, at the food system and governance levels, actors may have different interpretations of what constitutes the most critical challenge to address to support transition, as illustrated in the dairy sector (Thorsøe et al., 2020). In this transition context, inequalities may arise. For example, co-innovation processes centering farmers as co-producers of research in a living lab context without paying for their labor is emblematic of the imbalance in burden outlined in the conventional scenario. Given the European investment in living labs as an important model for the agricultural green transition, imbalances could grow despite attempts toward increased farmer participation, which might continue to include primarily privileged farmers.

The mission-oriented agricultural innovation systems approach highlights the direction-setting roles policymakers and the public sector have and emphasizes that it is essential to focus on who is excluded (Klerkx and Begemann, 2020). Greater inclusion in transition processes extended beyond the farmer to include a broader range of actors engaged in the food system, such as future farmers, eaters and activists could support more balanced transitions. A

transformative change model for understanding local food systems also emphasizes the power political, bureaucratic, and public spheres of actors hold in a process of transformative incrementalism (Buchan et al., 2019). According to Buchan et al. (2019), "the path to transformative change is long, incremental, and laden with power relations and struggles." This intriguing model is also supported by Klerkx and Begemann (2020), who assert that transformation is made up of small wins instead of sudden radical changes.

From a systems perspective, different roles and actions will be required at each level to enable holistic transformations in agriculture. Research and innovation are challenging to fund in farmer-led initiatives requiring governance and the converse for implementation. These three levels (governance, food, and farm) also have their own interpretation of problems and how they should be addressed. Even when addressing the same problem, farmers may focus on the lack of legume markets, food system actors may focus on processor standards, and governance may focus on the resource shortage. This highlights the limits of top-down or bottom-up coordination across levels as each operates within different codes of meaning. Alrøe and Noe (2014) offer a polycular framework to address wicked problems, supporting various codes of meanings in interdisciplinary research, moving from first to second order observation (which shares multi-perspective orientation of transdisciplinarity; Fernández González et al., 2021). By adopting perspectivism as a scientific philosophy, science is seen as observer-dependent and thus supports many concurrent scientific truths related to complex problems, which has important implications for an agricultural green transition.

5 Conclusion

Amid tensions between bottom-down and top-up approaches and between agency and structure, we assert that a balance of these components is relevant in the context of an agricultural green transition. We found that a commitment to rebalancing burden across governance, food and farm systems is essential for positive transformative change toward food system sustainability in Europe. The implications for governance structures include the need to incorporate a systems perspective and a transdisciplinary approach to balance multiple priorities and practices in a way that can be effectively translated to a variety of conditions at the farm scale. Given the diverse and changing nature of environmental and social landscapes in which farm systems operate, coherent yet place-based policies could deliver an enabling policy environment for the agricultural green transition. In this context, utilizing social theory and evidence-based practices within research and policy development processes is critical to overcoming challenges. Future transdisciplinary action research to analyze and recommend food and farm system scale policy schemes based on their system transition potential would be useful, but only if there is buy-in and willingness to adopt changes across levels of governance. Fostering environments where a diverse group of farmers, researchers and policymakers can co-create agendas for a sustainable future agriculture means acknowledging power dynamics within the present food system regime. Many stakeholders may also need to adopt new methodologies, skillsets, terminologies and even philosophies of science. Fine-tuning approaches to address sustainable transition challenges by applying them across governance, food and farm systems through iteration and compromise could support sustainable farming and enable the agricultural green transition desired by the European Green Deal.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

TS: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. VN: Conceptualization, Writing – original draft, Writing – review & editing. MT: Conceptualization, Writing – review & editing.

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Grammarly (v.1.2.94.1468) was utilized in the final proof read process to correct for grammatical errors.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aare, A. K., Lund, S., and Hauggaard-Nielsen, H. (2021). Exploring transitions towards sustainable farming practices through participatory research – the case of Danish farmers' use of species mixtures. *Agric. Syst.* 189:103053. doi: 10.1016/j.agsy.2021.103053

Allam, M., Radicetti, E., Ben Hassine, M., Jamal, A., Abideen, Z., and Mancinelli, R. (2023). A meta-analysis approach to estimate the effect of cover crops on the grain yield of succeeding cereal crops within European cropping systems. *Agriculture* 13:1714. doi: 10.3390/agriculture13091714

Alrøe, H. F., and Noe, E. (2014). Radical constructivism second-order science of interdisciplinary research a polyocular framework for wicked problems. Available at: https://philpapers.org/archive/ALRSSO.pdf (Accessed July 30, 2024).

Andersen, E., Henningsen, A., and Primdahl, J. (2017). "Denmark: implementation of new agri-environmental policy based on regulation 2078" in Agri-environmental policy in the European union. eds. H. Buller, G. A. Wilson and A. Höll (London: Routledge).

Bakker, E., Hassink, J., and van Veluw, K. (2023). The 'inner' dimension of Dutch farmers' trajectories of change: drivers, triggers and turning points for sustained agroecological practices. *Agroecol. Sustain. Food Syst.* 47, 687–717. doi: 10.1080/21683565.2023.2180563

Böcker, T., and Finger, R. (2016). European pesticide tax schemes in comparison: an analysis of experiences and developments. *Sustain. For.* 8:378. doi: 10.3390/su8040378

Boix-Fayos, C., and de Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European green Deal. *Agric. Syst.* 207:103634. doi: 10.1016/j.agsy.2023.103634

Buchan, R., Cloutier, D. S., and Friedman, A. (2019). Transformative incrementalism: planning for transformative change in local food systems. *Prog. Plan.* 134:100424. doi: 10.1016/j.progress.2018.07.002

Büchi, L., Wendling, M., Amossé, C., Necpalova, M., and Charles, R. (2018). Importance of cover crops in alleviating negative effects of reduced soil tillage and promoting soil fertility in a winter wheat cropping system. *Agric. Ecosyst. Environ.* 256, 92–104. doi: 10.1016/j.agee.2018.01.005

Burton, R. J. F. (2004). Seeing Through the 'Good Farmer's' Eyes: Towards Developing an Understanding of the Social Symbolic Value of 'Productivist' Behaviour. *Sociol. Rural.* 44, 195–215. doi: 10.1111/j.1467-9523.2004.00270.x

Burton, R. J. F., Forney, J., Stock, P., and Sutherland, L.-A. (2020). *The Good Farmer*. Routledge.

Carlile, P. R. (2004). Transferring, translating, and transforming: an integrative framework for managing knowledge across boundaries. *Organ. Sci.* 15, 555–568. doi: 10.1287/orsc.1040.0094

Colbach, N., and Dürr, C. (2003). Effects of seed production and storage conditions on blackgrass (*Alopecurus myosuroides*) germination and shoot elongation. *Weed Sci.* 51, 708–717. doi: 10.1614/P2002-051

Dalgaard, T., Hansen, B., Hasler, B., Hertel, O., Hutchings, N. J., Jacobsen, B. H., et al. (2014). Policies for agricultural nitrogen management—trends, challenges and prospects for improved efficiency in Denmark. *Environ. Res. Lett.* 9:115002. doi: 10.1088/1748-9326/9/11/115002

David, M. B., Drinkwater, L. E., and McIsaac, G. F. (2010). Sources of nitrate yields in the Mississippi River basin. *J. Environ. Qual.* 39, 1657–1667. doi: 10.2134/jeq2010.0115

Fernández González, C., Ollivier, G., and Bellon, S. (2021). Transdisciplinarity in agroecology: practices and perspectives in Europe. *Agroecol. Sustain. Food Syst.* 45, 523–550. doi: 10.1080/21683565.2020.1842285

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: responses to seven criticisms. *Environ. Innov. Soc. Transitions* 1, 24–40. doi: 10.1016/j.eist.2011.02.002

Geels, F. W. (2014). Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective. *Theory Cult. Soc.* 31, 21–40. doi: 10.1177/0263276414531627

Geels, F. W., Sovacool, B. K., Schwanen, T., and Sorrell, S. (2017). The socio-technical dynamics of low-carbon transitions. *Joule* 1, 463–479. doi: 10.1016/j.joule.2017.09.018

Gemtou, M., Kakkavou, K., Anastasiou, E., Fountas, S., Pedersen, S. M., Isakhanyan, G., et al. (2024). Farmers' transition to climate-smart agriculture: a systematic review of the decision-making factors affecting adoption. *Sustainability (Switzerland)* 16:2828. doi: 10.3390/su16072828

Glaze-Corcoran, S., Hashemi, M., Sadeghpour, A., Jahanzad, E., Keshavarz Afshar, R., Liu, X., et al. (2020). Understanding intercropping to improve agricultural resiliency and environmental sustainability. *Adv. Agron.* 162, 199–256. doi: 10.1016/bs.agron.2020.02.004

Guinet, M., Adeux, G., Cordeau, S., Courson, E., Nandillon, R., Zhang, Y., et al. (2023). Fostering temporal crop diversification to reduce pesticide use. *Nat. Commun.* 14:7416. doi: 10.1038/s41467-023-43234-x

Gunasinghe, N., Barbetti, M. J., You, M. P., Burrell, D., and Neate, S. (2020). White leaf spot caused by Neopseudocercosporella capsellae: a re-emerging disease of Brassicaceae. *Front. Cell. Infect. Microbiol.* 10:588090. doi: 10.3389/fcimb.2020.588090

Guerra, F., and Syed, M. D. (2024). Identifying mindsets for urban sustainability transformation: insights from Urban Labs. *Sustain. Sci.* 19, 523–537. doi: 10.1007/s11625-023-01437-7

Hakkarainen, V., Mäkinen-Rostedt, K., Horcea-Milcu, A., D'Amato, D., Jämsä, J., and Soini, K. (2022). Transdisciplinary research in natural resources management: towards an integrative and transformative use of co-concepts. *Sustain. Dev.* 30, 309–325. doi: 10.1002/sd.2276

Hauggaard-Nielsen, H., Lund, S., Aare, A. K., Watson, C. A., Bedoussac, L., Aubertot, J. N., et al. (2021). Translating the multi-actor approach to research into practice using a workshop approach focusing on species mixtures. *Front. Agric. Sci. Eng.* 8, 460–473. doi: 10.15302/J-FASE-2021416

Iversen, S. V., Dalgaard, T., and Graversgaard, M. (2024). Discordance between farmers and scientists – perspectives on nitrogen reduction measures in Denmark. *J. Environ. Manag.* 352:119877. doi: 10.1016/j.jenvman.2023.119877

Jensen, E. S., Chongtham, I. R., Dhamala, N. R., Rodriguez, C., Carton, N., and Carlsson, G. (2020). Diversifying European agricultural systems by intercropping grain legumes and cereals. *Int. J. Agri. Nat. Res.* 47, 174–186. doi: 10.7764/ijanr.v47i3.2241

Kathage, J., Smit, B., Janssens, B., Haagsma, W., and Adrados, J. L. (2022). How much is policy driving the adoption of cover crops? Evidence from four EU regions. *Land Use Policy* 116:106016. doi: 10.1016/j.landusepol.2022.106016

Klerkx, L., and Begemann, S. (2020). Supporting food systems transformation: the what, why, who, where and how of mission-oriented agricultural innovation systems. *Agric. Syst.* 184:102901. doi: 10.1016/j.agsy.2020.102901

Kronvang, B., Andersen, H. E., Børgesen, C., Dalgaard, T., Larsen, S. E., Bøgestrand, J., et al. (2008). Effects of policy measures implemented in Denmark on nitrogen pollution of the aquatic environment. *Environ. Sci. Pol.* 11, 144–152. doi: 10.1016/j.envsci.2007.10.007

Kumar, U., Thomsen, I. K., Eriksen, J., Vogeler, I., Mäenpää, M., and Hansen, E. M. (2023). Delaying sowing of cover crops decreases the ability to reduce nitrate leaching. *Agric. Ecosyst. Environ.* 355:108598. doi: 10.1016/j.agee.2023.108598

Lacombe, C., Couix, N., and Hazard, L. (2018). Designing agroecological farming systems with farmers: a review. *Agric. Syst.* 165, 208–220. doi: 10.1016/j.agsy.2018.06.014

Li, C., Stomph, T.-J., Makowski, D., Li, H., Zhang, C., Zhang, F., et al. (2023). The productive performance of intercropping. *Proc. Natl. Acad. Sci.* 120:e2201886120. doi: 10.1073/pnas.2201886120

Loorbach, D., Frantzeskaki, N., and Avelino, F. (2017). Sustainability transitions research: transforming science and practice for societal change. *Annu. Rev. Environ. Resour.* 42, 599–626. doi: 10.1146/annurev-environ-102014-021340

Madsen, H., Arnbjerg-Nielsen, K., and Mikkelsen, P. S. (2009). Update of regional intensity–duration–frequency curves in Denmark: tendency towards increased storm intensities. *Atmos. Res.* 92, 343–349. doi: 10.1016/j.atmosres.2009.01.013

Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., et al. (2021). Intercropping—a low input agricultural strategy for food and environmental security. *Agronomy* 11:343. doi: 10.3390/agronomy11020343

Marcillo, G. S., and Miguez, F. E. (2017). Corn yield response to winter cover crops: an updated meta-analysis. *J. Soil Water Conserv.* 72, 226–239. doi: 10.2489/jswc.72.3.226

Moss, S. (2017). Black-grass (*Alopecurus myosuroides*): why has this weed become such a problem in Western Europe and what are the solutions? *Outlooks Pest Manag.* 28, 207–212. doi: 10.1564/v28_oct_04

Nawaz, M. F., Bourrié, G., and Trolard, F. (2013). Soil compaction impact and modelling. A review. *Agron. Sustain. Dev.* 33, 291–309. doi: 10.1007/s13593-011-0071-8

Peeters, A., Lefebvre, O., Balogh, L., Barberi, P., Batello, C., Bellon, S., et al. (2020). A green deal for implementing agroecological systems: reforming the common agricultural policy of the European Union. *Landbauforschung* 70, 83–93. doi: 10.3220/LBF1610123299000

Rittel, H. W. J., and Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy. Sci.* 4, 155–169. doi: 10.1007/BF01405730

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., et al. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agron. J.* 97, 322–332. doi: 10.2134/agronj2005.0322a

Stone, T. F., Jerry Alford, J., Bečvářová, P. H., Eisa, M. A. M., El-Naggar, A. H., Espinosa, M. J. C., et al. (2024). Food system strategies to increase cereal-legume intercropping [manuscript submitted for publication]. Agroecology, Aarhus University.

Stone, T. F., and Thorsøe, M. H. (2024). Report on opportunities for intercropping species mixtures. [Report under review]. LEGUMINOSE Horizon Europe Project.

Sutherland, L. A., and Labarthe, P. (2022). Introducing 'microAKIS': a farmer-centric approach to understanding the contribution of advice to agricultural innovation. *J. Agric. Educ. Ext.* 28, 525–547. doi: 10.1080/1389224X.2022.2121903

Thorsøe, M., Noe, E., Maye, D., Vigani, M., Kirwan, J., Chiswell, H., et al. (2020). Responding to change: farming system resilience in a liberalized and volatile European dairy market. *Land Use Policy* 99:105029. doi: 10.1016/j.landusepol.2020.105029

Weituschat, C. S., Pascucci, S., Materia, V. C., Tamas, P., de Jong, R., and Trienekens, J. (2022). Goal frames and sustainability transitions: how cognitive lock-ins can impede crop diversification. *Sustain. Sci.* 17, 2203–2219. doi: 10.1007/s11625-022-01156-5

Wezel, A., Casagrande, M., Celette, F., Vian, J. F., Ferrer, A., and Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agron. Sustain. Dev.* 34, 1–20. doi: 10.1007/s13593-013-0180-7

Withers, P., Neal, C., Jarvie, H., and Doody, D. (2014). Agriculture and eutrophication: where do we go from Here? *Sustain. For.* 6, 5853–5875. doi: 10.3390/su6095853