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Grand challenges in designing and assessing agroecological cropping systems

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1 Introduction

Global crop production has increased with the increase in mechanisation and the use of pesticides and fertilisers since the 1960s (Faostat, 2020). Mechanisation allows farmers to till the soil more easily to manage weeds and prepare the seedbed for crops. Pesticides (e.g. herbicides, insecticides, fungicides) are used to control pests (e.g. weeds, insects, pathogens) likely to reach the potential crop productivity and quality that local conditions may deliver (Oerke, 2006). Synthetic fertilisers (e.g. ammonium nitrate, phosphate- and potash-based fertilisers) provide crops with the mineral elements essential for their growth and development, as close as possible to their needs. However, intensive use of tillage and the massive increase in the use of synthetic pesticides between 1990 and 2020 (+1 and +63 million tonnes in total for plant protection products and fertilisers respectively) are having a number of negative impacts, such as contributing to global warming (Ipcc, 2018), contaminating the environment and consequently losing biodiversity (Ipbes, 2019) and ecosystem services, and increasing public health problems.

To reduce the negative impacts of this intensification of agriculture, directives and international agreements have been promulgated and concluded (Directive 2009/128/Ce; Xu and Wang, 2023). The transition to sustainable agriculture (i.e. agriculture that can feed the population, is economically profitable and has little impact on the environment over the long term) is an objective that was already set out several decades ago (Reganold et al., 1990; Velten et al., 2015; Harwood, 2020). However, the use of pesticides and fertilisers has continued to rise between 1990 and 2020 (Faostat, 2020). Recently, the observation of negative impacts linked to climate change has reinforced the need to move towards sustainable agriculture. In 2020, the European Union launched the Farm to Fork strategy for a fairer, healthier and more environmentally-friendly food system (Moschitz et al., 2021; Fiore et al., 2022; Wesseler, 2022). This strategy is part of the European Green Deal that aimed at achieving climate neutrality in Europe by 2050. However, the transition to sustainable agricultural production, which is less reliant on pesticide, is taking time and, according to some studies, is not yet sufficiently advanced to achieve the targets set by the Green Deal (Guyomard et al., 2020).

2 Need for research in agroecology seen as a scientific discipline

Agroecology uses ecological concepts and principles for the design and management of agricultural systems (Altieri, 1995; Francis et al., 2003; Wezel et al., 2009). Agroecology started in the first half of the twentieth century as the overlay between agronomy and ecology, studying the ecology of crops and pests at the field-scale (Wezel et al., 2009; HLPE, 2019). From these modest beginnings, the scientific discipline of agroecology has become broader, more interdisciplinary, and increasingly popular.

Agroecology must be seen as a mix of means and objectives. Agroecological systems rely on cultivated and wild biodiversity as a mean of sustainable production, and in so doing are inspired by nature to imitate natural processes (Albert et al., 2017; Petit et al., 2018). The aim of agricultural practices is therefore to maximise the natural processes at work in the agroecosystem in order to derive maximum ecosystem services. All these services may not be provided on the same scale of time and space (Yvoz et al., 2022), and this is where agroecological management takes on a complex dimension. The objectives of the systems are multiple, and more importantly because the agricultural space (territory, landscape) is shared between various stakeholders. It is therefore a question of defining objectives, identifying variables to quantify them and assessing their value for the stakeholders in the territory. The design, assessment and production of knowledge on the effects of agro-ecological cropping systems therefore raise a number of challenges.

3 Crop diversification

Nowadays, agricultural production is often characterised by short rotations or sometimes monocultures. Among other things, this leads to a high incidence of pests and diseases, soil erosion and loss of fertility, pollution and reduced biodiversity (Perrin, 1976). In this context, crop diversification can help to improve agrobiodiversity and support the ecological processes required for the sustainable production of agricultural products (Guinet et al., 2023). Crop diversification is a key principle of the agroecological transition. It increases the production of healthy food and provides numerous ecosystem services. It is an essential link in the necessary transition of food systems.

The crop diversification can be done in space and time (Gaba et al., 2015; Hufnagel et al., 2020). The diversification of crops in space involves the establishment of two or more crops simultaneously over a certain period. The spatial arrangement of the two crops must be selected according to the available resources and the characteristics of the two crops. The association of the two crops with complementary morphological and physiological characteristics allows optimum use of all resources. For instance, the weeds have fewer resources to develop (Gu et al., 2021). The diversification of crops over time can be increased by the use of cover crop implemented between the harvest of the previous crop and the sowing of the next cash crop (Teasdale et al., 2007; Rouge et al., 2022). The use of cover crops can improve weed control during this period (Rouge et al., 2022) even if it does not always carry over in the next season (Adeux et al., 2021, 2023; Rouge et al., 2023) and offer significant and substantial benefits in terms of crop rotation (Sarrantonio and Gallandt, 2003; Marcillo and Miguez, 2017; Nouri et al., 2022).

Crop diversification in time and space remains to be assessed for its benefits (Vialatte et al., 2022; Guinet et al., 2023). It challenges the breeders to deliver new cultivars adapted to grow in complex canopies such as intercrops and cover crops. Finally, it challenges all the stakeholders along the value chain, to benefit from the diversity of crop and food produced in agroecological landscapes which may vary in term of quality and quantity over time and locations.

4 Reconnecting livestock and crop production

Many studies consider mixed farming as a model for Agroecology (Hendrickson et al., 2008; Bonaudo et al., 2014). However, mixed crop-livestock farms are declining sharply across the European Union and around the globe, mainly because of the high labour requirements needed to combine crops and livestock (Ryschawy et al., 2017). There is varying degrees of effective coordination between crops and livestock, ranging from simple coexistence to real synergy (Moraine et al., 2014). The combination of crops and livestock can create a virtuous cycle: the crops provide feed for the herd, whose manure amends the next crop. Mixed farming with livestock allows interactions, positive synergies, in particular by encouraging various favourable flows between crop and livestock farming activities within a given production unit. Mixed farming with livestock is able to provide a wide array of benefits that remains to be documented and assessed at the cropping system level. Crop diversification and cover cropping provide forage resources for livestock that in return provides fertility to the field through manure. In regions characterised by a high proportion of mixed farming with livestock, non-chemical strategies to control fungal diseases tended to increase (Lechenet et al., 2017a). Forage crops (*e.g.* silage maize and temporary grassland) are associated with low fungicide requirements and high biomass productivity (Lechenet et al., 2017a).

Research is needed to assess how much mixing crop with livestock among other agroecological principles can help farmers to redesign and improve the resilience, self-sufficiency, productivity, and efficiency of their systems. Research on agroecological cropping system should focus more on integrated crop–livestock systems (Bonaudo et al., 2014).

5 Numeric and machinery

Agricultural equipment and digital technology are essential levers for developing agroecological cropping systems, such as Pesticide-free cropping systems (Maurel and Huyghe, 2017; Ajena et al., 2022). Innovations in terms of precision of execution and adaptability of equipment is required. At the same time, the development of sensors will make it possible to improve the monitoring of pests and diseases, as well as the entire cropping system and its environment. Sensors, combined with new information technologies, could also contribute to the emergence of pesticide-free supply chains, facilitating traceability from field to plate. However, questions will have to be asked about the use of the vast amounts of data collected and the potentially high cost of the equipment.

Biocontrol is part of the agroecological levers to manage pests and should be considered as part of the integrated strategy at the cropping system and landscape scale (Cordeau et al., 2016; Dar et al., 2019). As far as biocontrol is concerned, innovations are needed so that biocontrol organisms and substances can be simply deployed at the same time as other with other actions (fertilisation, irrigation, weed control, etc.) and, if possible flexible and targeted according to needs. The aim of plant health epidemiosurveillance is to monitor the development of pests so that preventive or curative actions can be taken in good time. To be effective, four elements need to be monitored: the host, the pests, the beneficials and the environment. The digital technology should help strengthen this epidemiosurveillance in order to promote beneficial insects while managing pests. There is urgent needs to assess cropping systems that implement over the long run these technologies. Assessment must be made with multiple criteria in order to assess the sustainability of the pest management strategies.

6 Landscape agronomy and nature-based solutions

Agroecology requires thinking beyond the field scale to consider the positioning, quality and connectivity of fields and semi-natural habitats at larger spatial scales. The spatial and temporal organisation of semi-natural elements and the crop mosaic interact. Agricultural landscapes can be characterised by their composition, *i.e.* the nature, size or relative proportion of the elements and secondly according to their configuration, i.e. the structure, shape and spatial arrangement of these different elements (Turner, 1989; Dunning et al., 1992). The simplification of landscapes has a direct impact on species richness, particularly rare species, and accounts for 30% of the reduction in pollination efficiency and 50% of the reduction in natural pest regulation, with negative consequences for agricultural yields (Dainese et al., 2019).

There is an urgent need to think the management, design and assessment of agroecological cropping systems by considering interactions with habitats outside the field limits. We now know that what happens in a field partly depends on what happens around that fields. Designing agricultural practices without taking into account of the dominant practices in the area can cancel out the expected effects (Tscharntke et al., 2016). Redesigning and planning agricultural landscapes that would sustainably deliver services to agriculture has probably never been so high on the political and research agenda (Vanbergen et al., 2020; Vialatte et al., 2022). However, shifting to nature-based forms of agriculture with an emphasis on landscape design will require new models of research enhancing the integration of ecological and agronomical knowledge, targeting research for context-specific solutions, and increased empirical testing of design concepts (Petit et al., 2015, 2021).

For a long time, agronomists have designed and tested cropping systems on system experiments that test the system as a functional entity whose complexity is more than the sum of its parts (Lechenet et al., 2017b). Following the same philosophy, there is an urgent need for new experimental design that account for the design, management and assessment of semi-natural habitats, ecological infrastructures to enhance ecological processes at the field and landscape scale. We need a drastic shift in the way we see the role of farming from producing without deleterious effect on environment to regenerating resources and use of the diversity as a mean to produce sustainably.

7 Conclusion

Numerous authors have shown that the design of cropping systems on ecological functionalities requires new knowledge, a holistic approach at different spatial scales, and innovative design systems that combine scientific, technical and operational knowledge (Altieri, 1995; Francis et al., 2003; Warner, 2006; Gliessman, 2013). The agro-ecological transition therefore appears to be a complex innovation process, in which the technical changes embodied in agroecology are inextricably linked to changes in food, social, economic, institutional and political systems.

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Conflict of interest

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References

Adeux, G., Cordeau, S., Antichi, D., Carlesi, S., Mazzoncini, M., Munier-Jolain, N., et al. (2021). Cover crops promote crop productivity but do not enhance weed management in tillage-based cropping systems. *Eur. J. Agron.* 123, 126221. doi: 10.1016/j.eja.2020.126221

Adeux, G., Rodriguez, A., Penato, C., Antichi, D., Carlesi, S., Sbrana, M., et al. (2023). Long-term cover cropping in tillage-based systems filters weed community phenology: A seedbank analysis. *Field Crop Res.* 291, 108769. doi: 10.1016/j.fcr.2022.108769

Ajena, F., Bossard, N., Clément, C., Hibeck, A., Tiselli, E., Oehen, B., et al (2022). *Agroecology & Digitalisation: traps and opportunities to transform the food system.* (Brussels, Belgium: IFOAM Organics Europe). Available at: https://www.organicseurope.bio/content/uploads/2022/06/IFOAMEU_Agroecology_Digitalization_2020.pdf?dd.

Albert, C., Spangenberg, J. H., and Schröter, B. (2017). Nature-based solutions: criteria. *Nature* 543, 315–315. doi: 10.1038/543315b

Altieri, M. (1995). *Agroecology: the science of sustainable agriculture* (Boulder: Westview Press).

Bonaudo, T., Bendahan, A. B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., et al. (2014). Agroecological principles for the redesign of integrated crop–livestock systems. *Eur. J. Agron.* 57, 43–51. doi: 10.1016/j.eja.2013.09.010

Cordeau, S., Triolet, M., Wayman, S., Steinberg, C., and Guillemin, J.-P. (2016). Bioherbicides: Dead in the water? A review of the existing products for integrated weed management. *Crop Prot.* 87, 44–49. doi: 10.1016/j.cropro.2016.04.016

Dainese, M., Martin, E. A., Aizen, M. A., Albrecht, M., Bartomeus, I., Bommarco, R., et al. (2019). A global synthesis reveals biodiversity-mediated benefits for crop production. *Sci. Adv.* 5, eaax0121. doi: 10.1126/sciadv.aax0121

Dar, S. A., Khan, Z., Khan, A. A., and Ahmad, S. B. (2019). "Biopesticides–Its Prospects and Limitations: An Overview," in *Perspective in Animal Ecology and Reproduction*, vol. 296-314. (Astral International (P) Ltd, New Delhi, India).

Directive 2009/128/Ce European Parliament and the Council Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 Establishing a Framework for Community Action to Achieve the Sustainable Use of Pesticides. Available online at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0128.

Dunning, J. B., Danielson, B. J., and Pulliam, H. R. (1992). Ecological processes that affect populations in complex landscapes. *Oikos* 65, 169–175. doi: 10.2307/3544901

Faostat, F. (2020). Statistical databases (Rome, Italy: Food and Agriculture Organization of the United Nations). Available at: https://www.fao.org/faostat/en/.

Fiore, M., Sauvée, L., and Wiśniewska-Paluszak, J. (2022). Opportunities and challenges of EU farm-to-fork strategy. *Int. Food Agribusiness Manage. Rev.* 25, 703–707. doi: 10.22434/IFAMR2022.x001

Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., et al. (2003). Agroecology: The ecology of food systems. *J. Sustain. Agric.* 22, 99–118. doi: 10.1300/J064v22n03_10

Gaba, S., Lescourret, F., Boudsocq, S., Enjalbert, J., Hinsinger, P., Journet, E.-P., et al. (2015). Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. *Agron. Sustain. Dev.* 35, 607–623. doi: 10.1007/s13593-014-0272-z

Gliessman, S. (2013). Agroecology and food system transformation. *Agroecol Sustain. Food Syst.* 37, 1–2. doi: 10.1080/10440046.2012.734264

Gu, C., Bastiaans, L., Anten, N. P., Makowski, D., and van der Werf, W. (2021). Annual intercropping suppresses weeds: A meta-analysis. *Agricul Ecosyst. Environ.* 322, 107658. doi: 10.1016/j.agee.2021.107658

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

Guyomard, H., Bureau, J.-C., Chatellier, V., Détang-Dessendre, C., Dupraz, P., Jacquet, F., et al. (2020). "The Green Deal and the CAP: policy implications to adapt farming practices and to preserve the EU's natural resources," in *CAP and green deal–audition european parliament (AGRI)* (Rennes, France: INRAE). Available at: https://hal.inrae.fr/hal-03209246/document.

Harwood, R. R. (2020). "A history of sustainable agriculture," in *Sustainable agricultural systems*, vol. 3-19. (Boca Raton, USA: CRC Press).

Hendrickson, J. R., Hanson, J., Tanaka, D. L., and Sassenrath, G. (2008). Principles of integrated agricultural systems: Introduction to processes and definition. *Renewable Agric. Food Syst.* 23, 265–271. doi: 10.1017/S1742170507001718

HLPE. (2019). "Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition," in *A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.* (Rome). Available at: https://www.fao.org/3/ca5602en/ca5602en.pdf.

Hufnagel, J., Reckling, M., and Ewert, F. (2020). Diverse approaches to crop diversification in agricultural research. A review. *Agron. Sustain. Dev.* 40, 1–17. doi: 10.1007/s13593-020-00617-4

Ipbes (2019). *Summary for policymakers of the global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (Bonn, Germany: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services).

Ipcc (2018). *Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* Eds V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, W. M.-O. A. Pirani, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock and M. Tignor. (Cambridge, UK and New York, NY, USA: Cambridge University Press). doi: 10.1017/9781009157940.001

Lechenet, M., Dessaint, F., Py, G., Makowski, D., and Munier-Jolain, N. (2017a). Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nat. Plants* 3, 17008. https://www.nature.com/articles/nplants20178. doi: 10.1038/nplants.2017.8

Lechenet, M., Deytieux, V., Antichi, D., Aubertot, J. N., Barberi, P., Bertrand, M., et al. (2017b). Diversity of methodologies to experiment Integrated Pest Management in arable cropping systems: Analysis and reflections based on a European network. *Eur. J. Agron.* 83, 86–99. doi: 10.1016/j.eja.2016.09.012

Marcillo, G., and Miguez, F. (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

Maurel, V. B., and Huyghe, C. (2017). Putting agricultural equipment and digital technologies at the cutting edge of agroecology. *OCL* 24, D307. doi: 10.1051/ocl/2017028

Moraine, M., Duru, M., Nicholas, P., Leterme, P., and Therond, O. (2014). Farming system design for innovative crop-livestock integration in Europe. *Animal* 8, 1204–1217. doi: 10.1017/S1751731114001189

Moschitz, H., Muller, A., Kretzschmar, U., Haller, L., De Porras, M., Pfeifer, C., et al. (2021). How can the EU Farm to Fork strategy deliver on its organic promises? Some critical reflections. *EuroChoices* 20, 30–36. doi: 10.1111/1746-692X.12294

Nouri, A., Lukas, S., Singh, S., Singh, S., and MaChado, S. (2022). When do cover crops reduce nitrate leaching? A global meta-analysis. *Global Change Biol.* 28, 4736–4749. doi: 10.1111/gcb.16269

Oerke, E.-C. (2006). Crop losses to pests. *J. Agric. Cult.* 144, 31–43

Perrin, R. (1976). Pest management in multiple cropping systems. *Agro-Ecosystems* 3, 93–118. doi: 10.1016/0304-3746(76)90110-4

Petit, S., Cordeau, S., Chauvel, B., Bohan, D., Guillemin, J. P., and Steinberg, C. (2018). Biodiversity-based options for arable weed management. A review. *Agron. Sustain. Dev.* 38, 48. doi: 10.1007/s13593-018-0525-3

Petit, S., Deytieux, V., and Cordeau, S. (2021). Landscape-scale approaches for designing and assessing biodiversity-based agricultural systems enhancing biological pest control. *Environ. Monit. Assess.* 193, 75. doi: 10.1007/s10661-020-08812-2

Petit, S., Munier-Jolain, N., Bretagnolle, V., Bockstaller, C., Gaba, S., Cordeau, S., et al. (2015). Ecological intensification through pesticide reduction: weed control, weed biodiversity and sustainability in arable farming. *Environ. Manage.* 56, 1078–1090. doi: 10.1007/s00267-015-0554-5

Reganold, J. P., Papendick, R. I., and Parr, J. F. (1990). Sustainable agriculture. *Sci. Am.* 262, 112–121. doi: 10.1038/scientificamerican0690-112

Rouge, A., Adeux, G., Busset, H., Hugard, R., Martin, J., Matejicek, A., et al. (2022). Weed suppression in cover crop mixtures under contrasted levels of resource availability. *Eur. J. Agron.* 136, 126499. doi: 10.1016/j.eja.2022.126499

Rouge, A., Adeux, G., Busset, H., Hugard, R., Martin, J., Matejicek, A., et al. (2023). Carry-over effects of cover crops on weeds and crop productivity in no-till systems. *Field Crops Res.* 295, 108899. doi: 10.1016/j.fcr.2023.108899

Ryschawy, J., Martin, G., Moraine, M., Duru, M., and Therond, O. (2017). Designing crop–livestock integration at different levels: Toward new agroecological models? *Nutrient Cycling Agroecosyst* 108, 5–20. doi: 10.1007/s10705-016-9815-9

Sarrantonio, M., and Gallandt, E. (2003). The role of cover crops in North American cropping systems. *J. Crop Product* 8, 53–74. doi: 10.1300/J144v08n01_04

Teasdale, J., Brandsaeter, L., Calegari, A., and Neto, F. S. (2007). "Cover crops and weed management," in *Non chemical weed management principles. Concepts and Technology*, vol. 49-64. (CABI, Wallingford, UK).

Tscharntke, T., Karp, D. S., Chaplin-Kramer, R., Batáry, P., Declerck, F., Gratton, C., et al. (2016). When natural habitat fails to enhance biological pest control–Five hypotheses. *Biol. Conserv.* 204, 449–458. doi: 10.1016/j.biocon.2016.10.001

Turner, M. G. (1989). Landscape ecology: the effect of pattern on process. *Annu. Rev. Ecol. Systemat* 20, 171–197. doi: 10.1146/annurev.es.20.110189.001131

Vanbergen, A. J., Aizen, M. A., Cordeau, S., Garibaldi, L. A., Garratt, M. P. D., Kovács-Hostyánszki, A., et al. (2020). Transformation of agricultural landscapes in the Anthropocene: Nature's contributions to people, agriculture and food security. *Adv. Ecol. Res.* 63, 193–253. doi: 10.1016/bs.aecr.2020.08.002

Velten, S., Leventon, J., Jager, N., and Newig, J. (2015). What is sustainable agriculture? A systematic review. *Sustainability* 7, 7833–7865. doi: 10.3390/su7067833

Vialatte, A., Tibi, A., Alignier, A., Angeon, V., Bedoussac, L., Bohan, D., et al. (2022). Promoting crop pest control by plant diversification in agricultural landscapes: a conceptual framework for analysing feedback loops between agro-ecological and socio-economic effects. *Adv. Ecol. Res.* 65, 133–165. doi: 10.1016/bs.aecr.2021.1010.1004

Warner, K. D. (2006). Extending agroecology: Grower participation in partnerships is key to social learning. *Renewable Agric. Food Syst.* 21, 84–94. doi: 10.1079/RAF2005131

Wesseler, J. (2022). The EU's farm-to-fork strategy: An assessment from the perspective of agricultural economics. *Appl. Economic Perspect. Policy* 44, 1826–1843. doi: 10.1002/aepp.13239

Wezel, A., Bellon, S., Dore, T., Francis, C., Vallod, D., and David, C. (2009). Agroecology as a science, a movement and a practice. A review. *Agron. Sustain. Dev.* 29, 503–515. doi: 10.1051/agro/2009004

Xu, J., and Wang, J. (2023). Analysis of the main elements and implications of the Kunming-Montreal Global Biodiversity Framework. *Biodiversity Sci.* 31, 23020. doi: 10.17520/biods.2023020

Yvoz, S., Cordeau, S., and Petit, S. (2022). Enhancing weed multifunctionality at a landscape scale: A simulation study. *Landscape Urban Plann.* 228, 104589. doi: 10.1016/j.landurbplan.2022.104589