Landbauforschung
Journal of Sustainable and Organic Agricultural Systems

Vol. 70 (2) 2020

# Agroecology: Can we change our food systems?

**Landbauforschung**
**Journal of Sustainable and Organic Agricultural Systems**

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Landbauforschung is peer-reviewed and indexed in: CAB International, Science Citation Index Expanded, Current Contents/Agriculture, Biology & Environmental Sciences, Scopus, Web of Science.

Publisher
Johann Heinrich von Thünen Institute,
Institute of Organic Farming

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Cover photos
Roman Maerzinger/stock.adobe.com (front), Thünen Institute/Hans Marten Paulsen (back)

ISSN 2700-8711



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**Research articles** present original new research results. The material should not have been previously published elsewhere. The novelty of results and their possible use in further development of sustainable and organic agricultural systems should be clearly claimed.

**Review articles** present new overviews generated from existing scientific literature to analyse the current state of knowledge. Conclusions on necessary consequences for further sustainable development of agricultural systems and research needs shall be drawn.

**Position Papers** present science-based opinions on new, or possibly disruptive, developments in sustainable agricultural systems. Authors should use scientific references to validate and approve arguments for a position. These papers shall allow the reader to understand controversial positions and to find an own position.

Interdisciplinary contributions, approaches and perspectives from all scientific disciplines are needed and welcome to cover the broad scope of the journal. We also aim at publishing review processes and positions in agreement with the authors. Authors are responsible for the content of their articles and contributions. The publishers are not liable for the content.

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**Agroecology – Can we change our food systems?**

The strict integration of agro-ecological concepts into food production is fundamental for combining local resources with agricultural production. It is also essential for securing the future stability of our global and local food systems. Food sovereignty, meaning independent selection, production and consumption of food products, can be a driving idea for local action. But both small holder farmers in local markets as well as farmers in globalized markets need perspectives for their future existence, for the stability of their systems, and multidimensional goals for production – including, for example, high efficiency and nature protection. This field is wide and not really new – but comprehensive ideas for scientific, practical and social development are still needed.

Tell us about your experiences in and visions for this field. 1) How can agroecosystems be stabilised to generate and secure future food production and income for the farmers? 2) Can agriculture be improved to be a future basis for local work and wealth? 3) What do farming systems based on agroecology concepts look like? 4) What strategies foster the integration of those concepts and the future transition of agriculture?

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# Editorial

## Agroecology – Can we change our food systems?

For the editorial team
Hans Marten Paulsen
Chief editor Landbauforschung
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As guest editor
Jens Dauber
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*Thünen Institute of Biodiversity, Germany*


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## Dear colleagues, authors, reviewers and readers!

Over the past decades, maintaining and increasing the productivity of farming per hectare to secure the quantity of food and feed was the core objective of food production worldwide. This objective was achieved mainly through technological innovations, including efficient machinery, breeding, and chemical inputs such as fertilisers and pesticides. The structure of the value chain pushed the specialisation of farming on towards the production of a limited number of crops, while supplies, processing and marketing were concentrated to a few cooperatives, agro-industry and retail. This evolutionary development had been appraised as successful in ensuring food security, up to the point where environmental and social trade-offs became apparent. The narrow perspective of food security, with a focus on food quantity, may therefore have to be replaced by a new comprehensive approach to value food sustainability. An exemplary approach can be found in the recently published 'Farm to Fork Strategy' of the European Commission.

But the development of circular bio-based economies, improved animal welfare, and gains in biodiversity and ecosystem services are still in their infancy in many parts of Europe and need to be developed worldwide. A transition of food production towards systems with reduced dependency on pesticides and antimicrobials, reduced excess fertilisation, and skillful use of natural resources as well as fair participation by local communities and people must be sought. Research and movements on agroecology are trying to develop solutions in this multifaceted field, where changes are determined by nature, technology and various actors.

With the call for the current issue of Landbauforschung – *Journal of Sustainable and Organic Agricultural Systems*, we asked for strategies and success stories on the integration of agroecology to foster sustainability in agriculture. We received a vast range of position papers on the future role of agroecology in designing a new approach to agriculture and agricultural policy. Many authors provided reports on local successes, visions for research design as well as positions and results on the effects of integration of modern techniques or on more traditional changes in management of farming and food systems.

The review process – it is published in detail together with the articles – discloses that many of the discussions on how to succeed in strictly integrating agroecology concepts in developing sustainable agriculture for the future are ongoing.

We hope that the collection of articles will capture your interest and that it will help to generate a common understanding what agroecology means. We hope it helps the reader to learn about different experiences with agroecology and views on how it might to be used to improve sustainability in agriculture.

*Hans Marten Paulsen and Jens Dauber*

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# Contents

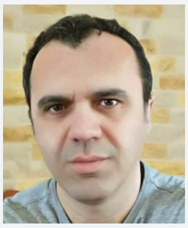
## Agroecology – Can we change our food systems?

POSITION PAPER

# Digital innovations for the agroecological transition: A user innovation and commons-based approach

Vasileios D. Gkisakis[1] and Konstantinos Damianakis[2]

Received: February 19, 2020
Revised: April 7, 2020
Accepted: May 6, 2020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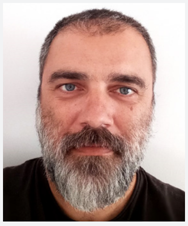
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KEYWORDS **agroecology, digitalisation, innovation, transition, commons**

Agroecology is currently an emerging concept for the transition towards sustainable and resilient food systems, with a significant body of literature on how to accomplish such a transit following a systemic and holistic approach (Pimbert, 2015; Altieri et al., 2017). Most transition analyses are based on what MacRae et al. (1990) presented to be a linear stepwise process of increased efficiency of the use of agricultural inputs, followed by their substitution, and eventually the whole system redesign, focusing equally at the farm and the greater territorial level (Gliessman, 2015). Such a process is meant to be knowledge-intensive, where employment of several innovative frameworks, tools, and technologies, re-directed towards sustainability principles, could potentially be used (Rains et al., 2011; Caron et al., 2014). Indeed, quite a few agricultural technologies are widely described as being aligned with this path of transition, while most recent mainstream narratives of agricultural innovation propose a variety of "disruptive" technological fixes for increasing the efficiency of the food system (Gkisakis et al., 2017).

Digitalisation in agriculture (DiA) is top-placed among these technological propositions as a term that collectively describes the multitude of concepts and forms of digital technologies applied in agriculture, also known as 'smart farming', 'precision agriculture', or 'digital agriculture'. DiA is defined as the socio-technical process of applying digital innovations in agricultural production systems and value chains (Klerkx et al., 2019). It comprises "technocentric" approaches of gradual to extreme mechanisation of farm management, supported by data-driven procedures and sophisticated tools and technologies, such as information and communication technology platforms, big data, the Internet of things, drones, robotics, sensors, or artificial intelligence. DiA approaches are often regarded as highly prestigious solution-providers that increase yields, reduce costs, and, notably, promote agricultural sustainability (Barilla CFN, 2017). They have also become a prioritised trend in the EU and global rural development policies and supported applied research topics in order to facilitate the creation of a market players' ecosystem, including manufacturers, researchers, and infrastructure providers, and ensure the rise of a novel economic sector (European Commission, 2019).

Despite the technological optimism, warnings are often expressed about how the ultimate objective of systemic redesign could be compromised by adopting approaches that simply focus on input-substitution and efficiency increase, eventually containing the risk of "conventionalisation" of the agroecological transition process (Darnhofer et al., 2010; Caron et al., 2014; Duru et al., 2015). This argument has rather advanced the discussion among stakeholders on the differentiation of agroecology from other approaches regarded

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as likewise sustainable (e.g. climate-smart agriculture or sustainable intensification), in order to avoid possible co-optation by the mainstream agricultural trends (Pimbert, 2015; Altieri et al., 2017). However, a conclusive consensus has not been reached with regards to the potential role of DiA in the agroecological transition towards truly sustainable and resilient food systems.

For almost a decade, the application of digital technologies has been related to the so-called "weak" form of ecological modernisation, which promotes an interventionist and "therapeutic" strategy, in continuity with production-oriented approaches that still rely on external chemical inputs (Horlings and Marsden, 2011; Rains et al., 2011). Contrariwise, the "strong" form of ecological modernisation, also described as "biodiversity-based agriculture", is featured to support agroecology (Duru et al., 2015), by enhancing the provision of agroecosystem services mainly through practices and farming systems that are based on biodiversity attributes. Furthermore, DiA has been shown to only partially improve the efficiency of inputs and resource use or decrease production costs (Duru et al., 2015). This is accompanied by high costs of farm management mechanisation that require large initial investments in time and capital (Van Meensel et al., 2012) and consequently exclude small scale farmers that may not take advantage of the new technologies (Osipov and Bogoviz, 2017).

DiA approaches have also been described as valuing mostly the big data and technology transfer models, rather than promoting an experience-based exchange of knowledge and long-term observation of ecological processes (Carolan, 2017; Higgins et al., 2017; Gkisakis et al., 2017). In fact, mainstream agricultural digitalisation appears to be more aligned to a top-down paradigm, centred on and driven by technology developers. Under this approach, users are considered as a mere market (Kshetri, 2014; Seppala, 2014), which eventually generates a considerable gap between innovation development and the context, needs, assets, and emerging constraints faced by farmers (Bellon and Ollivier, 2018). Thus, it is stressed by several authors that DiA tends to ignore any resulting economic and cognitive dependencies of farmers, especially small ones, to technology providers, which may lock both food producers as well as citizens into asymmetrical power relationships and lead to the loss of autonomy (Gkisakis et al., 2017; Higgins et al., 2017; Carolan, 2018).

Despite the above, other authors (Maurel and Huyghe, 2017) emphasise the positive aspects of digital technologies and include DiA among the broad technological possibilities that will help meet the challenges of agroecological transition; as such, DiA is expected to make a multi-level contribution to farming efficiency that would help farmers close the loop of biochemical flows or take advantage of biodiversity. Ingrand (2018) also states that the combination of agroecology and DiA would minimise the risks of failure for both, in comparison to a model of separate development. For agroecology, this would mean a reduction of the risk of having limited capacity to motivate different actors due to its low-tech nature; for digital sciences and other new technologies, this would mean avoiding the risk of social rejection due to the mechanisation tendencies associated with several technological actors while excluding farmers. Other recent related reports (Rudram et al., 2016; HPLE, 2019; Kipling and Becoña, 2019) aptly stress that digital tools and technologies, like mobile phones and Internet, provide opportunities for improved information exchange, knowledge-sharing, and co-production. Therefore, they potentially facilitate farmer-to-farmer exchanges in various countries, including low-income ones, as well as increase the ability to establish shorter food chains and build trust among farmers and consumers.

To move beyond such conflicting dissensions and in order to provide a pragmatic, transdisciplinary approach, we argue that digital technologies could play a potential complementary role in the agroecological transition, only when certain prerequisites, previously described by data science and socioeconomic disciplines, are met:

i) A user innovation (UI) process should be applied, emphasising the end-user's involvement (in our case – the farmers) in digital tool and technology development. UI is regarded to be fundamentally different from the traditional, manufacturer-centric model, where products and services are developed by manufacturers in an exclusive way (von Hippel, 2005). Instead, it stresses the end-users' ability to either innovate for themselves in a do-it-yourself manner that goes beyond a simple participatory approach or co-innovate by benefiting from freely open-shared innovations, consequently organising participation at multiple levels and take advantage from collective intelligence and organisational structure in a non-exclusive manner (Ornetzeder and Rohracher, 2006). Therefore, UI has been regarded as representing the democratisation of innovation development, where users possess the unique local knowledge of their needs and the technical capacity to create follow-on innovations to meet these needs (Douthwaite, 2002). Examples of agricultural technologies, including digital ones, developed by or co-developed with users are already abundant, and an essential next step proposed would be their scaling up and scaling out (Cerf et al., 2012; Van Meensel et al., 2012; Lindblom et al., 2017).

ii) A peer-to-peer (P2P) process of sharing innovation should be followed, incorporating its diffusion to non-innovators (Gambardella et al., 2017) within a commons-based peer production (CBPP) model, as described by Benkler and Nissenbaum (2006). P2P represents a relational dynamic of human interaction requiring a decentralised and non-hierarchical network organisation with the aim of communicating, collaborating, creating, and exchanging value (Bauwens and Pantazis, 2018), such as, in the case of DiA, the value generated by technology and data use. Within CBPP, the P2P process is further advanced, leading to a mutual contribution by stakeholders and creating a common pool of either innovative knowledge, tools or design, through participatory governance open to further contributions (Bauwens, 2014). CBPP is already exemplified in cases related to DiA, including open source agricultural technology initiatives, such as Farm Hack (USA), collaborative projects for the creation of technology solutions and innovation by farmers (L'atelier paysan, France), or even research projects like CAPSELLA of EU's H2020 programme (Gkisakis et al., 2017). Importantly, such approaches, characterised by impartiality, provision of advice and information, and independence from private-sector sources, have been reported as being highly appreciated by the farming community (Knierim et al., 2018).

To conclude, a broad consensus on the role of digital innovations in agroecology has not been reached as many stakeholders strongly argue that DiA is not expected to be one of the main drivers for the agroecological transition, at least not like other core-features, such as the enhancement of agroecosystems and biodiversity management. Nevertheless, digitalisation could potentially comply with agroecological principles when a combination of user innovation processes and a commons-based peer production model is applied. This would redirect the development and application of the emerging digital technologies towards an approach that contains the immediate farmers' involvement and a horizontal transfer of innovative knowledge among stakeholders, as part of a holistic management strategy for sustainably redesigning the food system.

## REFERENCES

Altieri M, Nicholls CI, Montalba R (2017) Technological approaches to sustainable agriculture at a crossroads: an agroecological perspective. Sustainability 9(3):349, doi:10.3390/su9030349

Barilla CFN, Barilla Center for Food and Nutrition (2017) Smart farming: the new "green revolution" [online]. Retrieved from <https://www.barillacfn.com/en/magazine/food-and-sustainability/smart-farming-the-new-green-revolution-/> [at 1 Sept 2017]

Bauwens M (2014) Commons based peer production: an introduction [online]. Retrieved from <https://www.boell.de/en/2014/07/08/commons-based-peer-production-introduction> [at 8 July 2014]

Bauwens M, Pantazis A (2018) The ecosystem of commons-based peer production and its transformative dynamics. Sociol Rev 66(2):302–319, doi:10.1177/0038026118758532

Bellon S, Ollivier G (2018) Institutionalizing agroecology in France: social circulation changes the meaning of an idea. Sustainability 10(5):1380, doi:10.3390/su10051380

Benkler Y, Nissenbaum H (2006) Commons-based peer production and virtue. J Polit Philos 14(1):394–419, doi:10.1111/j.1467-9760.2006.00235.x

Carolan M (2017) Publicising food: big data, precision agriculture, and co-experimental techniques of addition. Sociol Ruralis 57(2):135–154, doi:10.1111/soru.12120

Carolan M (2018) 'Smart' farming techniques as political ontology: Access, sovereignty and the performance of neoliberal and not-so-neoliberal worlds. Sociol Ruralis 58(4):745–764, doi:10.1111/soru.12202

Caron P, Biénabe E, Hainzelin E (2014) Making transition towards ecological intensification of agriculture a reality: the gaps in and the role of scientific knowledge. Curr Opin Environ Sustain 8:44–52, doi:10.1016/j.cosust.2014.08.004

Cerf M, Jeuffroy MH, Prost L, Meynard JM (2012) Participatory design of agricultural decision support tools: taking account of the use situations. Agron Sustain Dev 32:899–910, doi:10.1007/s13593-012-0091-z

Darnhofer I, Fairweather J, Moller H (2010) Assessing a farm's sustainability: insights from resilience thinking. Int J Agr Sustain 8(3):186–198, doi:10.3763/ijas.2010.0480

Douthwaite MB (2002) Enabling innovation: A practical guide to understanding and fostering technological change. London, New York: Zed Books, 266 p

Duru M, Therond O, Fares M (2015) Designing agroecological transitions; a review. Agron Sustain Dev 35:1237–1257, doi:10.1007/s13593-015-0318-x

European Commission (2019) Building a European Data policy [online]. Retrieved from <https://ec.europa.eu/digital-single-market/en/policies/building-european-data-economy> [at 7 Febr 2020]

Gambardella A, Raasch C, von Hippel E (2017) The user innovation paradigm: Impacts on markets and welfare. Manag Sci 63(5):1450–1468, doi:10.1287/mnsc.2015.2393

Gkisakis V, Lazzaro M, Ortolani L, Sinoir N (2017) Digital revolution in agriculture: fitting in the agroecological approach? [online] Agroecology Greece. Retrieved from <www.agroecology.gr/ictagroecologyEN.html> [at 20 Dec 2017]

Gliessman SR (2015) Agroecology: The ecology of sustainable food systems, 3rd Edition. New York: CRC Press/Taylor & Francis, 406 p

Higgins V, Bryant M, Howell A, Battersby J (2017) Ordering adoption: materiality, knowledge and farmer engagement with precision agriculture technologies. J Rural Stud 55:193–202, doi:10.1016/j.jrurstud.2017.08.011

Horlings LG, Marsden TK (2011) Towards the real green revolution? Exploring the conceptual dimensions of a new ecological modernisation of agriculture that could "feed the world". Global Environ Chang 21(2):441–452, doi:10.1016/j.gloenvcha.2011.01.004

HPLE, The High Level Panel of Experts on Food Security and Nutrition (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition [online]. Rome: FAO. HLPE 14. Retrieved from <http://www.fao.org/agroecology/database/detail/en/c/1242141/> [at 21 June 2019]

Ingrand S (2018) Opinion paper: 'monitoring *te salutant*:'combining digital sciences and agro-ecology to design multi-performant livestock farming systems. Animal 12(1):2–3, doi:10.1017/S1751731117001999

Kipling RP, Becoña G (2019) Applying a conceptual framework for effective implementation of on-farm greenhouse gas mitigation: Evaluation of knowledge exchange methods in Wales and Uruguay. Landbauforsch J Sustainable Organic Agric Syst 69(1):13–24, doi:10.3220/LBF1581687621000

Klerkx L, Jakku E, Labarthe P (2019) A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS-Wagen J Life Sc 90–91:100315, doi:10.1016/j.njas.2019.100315

Knierim A, Borges F, Kernecker M, Kraus T, Wurbs A (2018) What drives adoption of smart farming technologies? Evidence from a cross-country study [online]. In: Proceedings of the European International Farm Systems Association (IFSA) Symposium, Chania, Greece, 1–5 July 2018:1–14. Retrieved from <http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2018/Theme4_Knierim.pdf> [at 14 July 2020]

Kshetri N, (2014) The emerging role of Big Data in key development issues: Opportunities, challenges, and concerns. Big Data Soc. 1(2)1–20; doi:10.1177/2053951714564227

Lindblom J, Lundström C, Ljung M, Jonsson A (2017) Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies. Precis Agric18:309-331, doi.org/10.1007/s11119-016-9491-4

MacRae RJ, Hill SB, Mehuys GR, Henning J (1990) Farm-scale agronomic and economic conversion from conventional to sustainable agriculture. Adv Agron 43:155–198), doi:10.1016/S0065-2113(08)60478-2

Maurel VB, Huyghe C (2017) Putting agricultural equipment and digital technologies at the cutting edge of agroecology. OCL 24(3):D307, doi:10.1051/ocl/2017028

Ornetzeder M, Rohracher H (2006) User-led innovations and participation processes: lessons from sustainable energy technologies. Energy policy 34(2),138–150, doi:10.1016/j.enpol.2004.08.037

Osipov VS, Bogoviz AV (2017) Transition to digital agriculture: background, roadmap and possible implications. Econ Agric Russ 10:11–15

Pimbert M (2015) Agroecology as an alternative vision to conventional development and climate-smart agriculture. Development 58(2–3):-286–298, doi:10.1057/s41301-016-0013-5

Rains GC, Olson DM, Lewis WJ (2011) Redirecting technology to support sustainable farm management practices. Agric Syst 104(4):365–370, doi:10.1016/j.agsy.2010.12.008

Rudram B, Faith B, Prieto Martín P, Ramalingam B (2016) The impact of digital technology on environmental sustainability and resilience: An evidence review [online]. Brighton: IDS, 61 p, Evidence Report No 209. Retrieved from <https://opendocs.ids.ac.uk/opendocs/bitstream/handle/

20.500.12413/12661/ER209_TheImpactofDigitalTechnologyonEnvironmentalSustainabilityandResilience.pdf?sequence=1> [at 15 July 2020]

Seppala TJ (2014) Monsanto pushes Big Data-driven planting but farmers are skeptical [online]. Retrieved from <https://www.engadget.com/2014/02/26/monsanto-prescriptive-farming/> [at 15 July 2020]

Van Meensel J, Lauwers L, Kempen I, Dessei J, Van Huylenbroeck G (2012) Effect of a participatory approach on the successful development of agricultural decision support systems: The case of Pigs2win. Decis Support Syst 54(1):164–172, doi:10.1016/j.dss.2012.05.002

Von Hippel E (2005) Democratizing innovation: The evolving phenomenon of user innovation. JFB 55:63–78, doi:10.1007/s11301-004-0002-8

POSITION PAPER

# Local sustainable diets as a driver of the transition to agroecological food systems

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Received: March 10, 2020
Revised: May 29, 2020
Accepted: July 22, 2020

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KEYWORDS **local diets, sustainable diets, agroecology transition, food systems**

In this paper, we propose the promotion of local sustainable diets as a process that can facilitate the transition of current industrialised food systems to agroecological food systems. First, we describe the problem, which can be synthesised by the following question: how to enhance the synergies between local diets, sustainable diets, and agroecology that we argue are the key drivers of the transition to agroecological food systems. To build our argument, we first provide a theoretical discussion regarding the concepts of sustainable diets, local diets, agroecology practice, agroecology transition, and sustainable food systems. This discussion allows us for the identification of joint and complementary characteristics. We then provide possible solutions based on existing global experiences, which we believe to drive the development of local and sustainable diets, agroecology, and food systems and taken together can aid the transition to agroecological food systems.

## 1 Description of the problem

As defined by the FAO (2012), sustainable diets are characterised by the following five dimensions: i) protection and respect of biodiversity and ecosystems, ii) cultural acceptance, iii) accessibility, economic fairness, and affordability, iv) nutrition, safety, and health and v) optimisation of natural and human resources. Sustainable diets have low environmental impacts and guarantee food and nutrition security and health for both the present and future generations. A sustainable diet is related to the concept of sustainable food systems. A sustainable food system is the sum of the elements, activities, and actors that are interrelated around the production, transformation, distribution, and consumption of food, in a way that delivers food security and nutrition but does not jeopardise social, economic, or environmental sustainability (FAO, 2018). But are sustainable diets inextricably linked to sustainable food systems? What are the cause and effect relationships between sustainable diets and sustainable food systems, and are they reciprocal? Diet has a direct impact on consumers' food choices and determine which foods are transformed, produced, and thus distributed throughout the food supply for consumer purchase. But this is a two-way process as food production shapes food product transformation and distribution, subsequently affecting the food supply and hence what consumers can choose from to be part of their diet (Meybeck and Gitz, 2017). Therefore, a sustainable diet will, ideally, enhance a sustainable food system through consumer choices as production and distribution will have an incentive to adapt and supply sustainable foods. However, consumers can only implement a sustainable diet if the food production and distribution provide them with both economically and physically accessible sustainable food options.

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There is no universal concept of local diet as there are myriad definitions and understandings of the term 'local'. In general, a local diet is one that is based on locally produced and sourced foods (Hunter et al., 2020). However, there is no single agreed-upon idea of what the distance should be between the farmer and the consumer for considering food as locally grown; some argue 10, 50, or up to 100 miles, others a day's drive, or within state borders (Whitney and Rolfes, 2019). In our opinion, local diets should be based on foods produced within the lowest distance possible between farmers and consumers. But are local diets always sustainable? Local food production might not coincide with a low environmental impact or, if it does, the outcome might not be enough to feed the entire population, for instance, in areas with severe climatic constraints. Therefore, we emphasise the concept of local sustainable diets. We argue that local diets also need to be sustainable and vice versa so that what is sustainable is also accessible.

Local sustainable diets will facilitate the agroecology transition (AET), which in turn will help maintain local sustainable diets by ensuring agroecological production. Specifically, agroecology is the science of sustainable agriculture, with a focus on the production system (Altieri, 1995). Agroecology as a type of agricultural practice recognises and uses the relation between socio-cultural characteristics and the food system as a powerful tool; thus, it requires a solid base of local knowledge. Bezner Kerr et al. (2019) specify that the practice of agroecology has relied on approaches to food production based on local knowledge, culture, and values. The AET is a process of systemic transformation to the ecologisation of agriculture and food (Bergez et al., 2019). Ultimately, the AET is a shift to a socio-technical system that is radically different from that used in current industrialised agro-food production. The AET is often addressed as a redesign at the farm level, but Ollivier and colleagues argue it should be understood more broadly; as an alignment of farmers' needs, ecosystem processes, and societal needs and demands (e.g. health impact or food price) (Ollivier et al., 2018). A true AET involves long-term changes in a range of elements and dimensions (e.g. technology, commercialisation, consumption) enacted by myriad actors and social groups (e.g. consumers, farmers, public institutions) (Köhler et al., 2019). Therefore, we propose that the development of local sustainable diets includes elements, which we will refer to as key drivers, with the potential to drive food systems through the long-term process of the AET. We recognise that it is difficult to make a modern industrialised food system completely agroecological, especially if we refer to a large geographic territory. However, we assert that the AET is a process with an inspiring goal, even though it is almost impossible to fully complete. The AET of food systems requires forces that underpin the proximity among actors in the food system, such as the close geographic relationships between farmers and consumers for food purchases necessary for the provision of local sustainable diets. Furthermore, we argue that local sustainable diets and the AET are not instantly concomitant but have key common elements that will, ideally, function in a synergic way.

How can then local sustainable diets contribute to the long-term process for the AET of food systems? From the above, we conclude that the AET of food systems must include, among others, three key elements: 1) be participatory, 2) be consistent with socio-cultural aspects, and 3) value the locally available resources. The strong link between the actors in the food system and the spatial area in which they interact to help shape local sustainable diets has the potential to drive all three of these elements. However, in the current expansion of modern food systems that moves producers and consumers away from each other, how can we in practice both recover and maintain local sustainable diets? We believe that the practice of agroecology offers potential solutions for helping to create and maintain local sustainable diets in a population. What follows are some practical examples and recommendations (i.e. possible solutions) from the literature to illustrate how to enhance the commonalities and potential synergies between local sustainable diets and agroecology practice and thus drive the transition towards agroecological food systems.

## 2 Possible solutions

Worldwide, on a sub-national level, both political and programmatic strategies have been proposed by city governments, especially in the developed countries, to reshape the food supply according to proximity and sustainability criteria. According to Köhler et al. (2019), public policies must play a central role in sustainable transitions, such as the AET, considering that sustainability is a public good. The participation of cities in food governance facilitates the adaptation of the food system to local needs (Sonnino, 2016). The promotion of peri-urban agriculture and short food supply chains has the potential to provide the inputs for city-driven food systems based on local products. Through facilitating distribution from farms to nearby cities and providing farmers with a stable income source, farmers are more likely to be a part of city-driven food systems. One mechanism that facilitates city-driven food systems is through Community Supported Agriculture (CSA), which consists of consumers providing farmers with money upfront prior to the harvest in return for weekly or monthly allotments of agricultural products. The CSA mechanism was originated in Europe in the 60s and 70s to support biodynamic farms. Hvitsand (2016) suggests that the producers and consumers committed to CSA are often concerned with aspects in line with agroecology principles. After analysing 22 countries as cases, Volz et al. (2016) found that European CSA strongly incorporates agroecology practices. Taken together, CSA is a way to promote local sustainable diets by bringing farmers and consumers closer together. We suggest that this proximity may help drive the AET as consumers could have the opportunity to ask farmers for foods produced under certain conditions, such as through agroecology practices.

The promotion of Participatory Guarantee Systems (PGS) can complement CSA by guaranteeing consumers that the local foods they receive are agroecological, as well as enhancing the trust, networking, and knowledge exchange between farmers and consumers. PGS are an alternative to the third-party certification for organic and agroecological farming. Third-party certification worldwide is a paid service in the hands of certification companies and responds to the organic farming standards of the destination market. In contrast, according to the IFOAM (2014), in PGS the stakeholders – farmers and consumers – together oversee organic and agroecological certification. There are more than 240 PGS initiatives operating in 67 countries that involve more than 310,000, mostly small-scale, farmers. However, only 11 countries worldwide recognise PGS certifications as a legal equivalent to third party certifications (Willer and Lernoud, 2019). The use of PGS helps to promote local sustainable diets by providing a greater amount of certification mechanisms, beyond that of 'certified organic', to signal to a consumer that the food product was produced under agroecological conditions. Therefore, the use of PGS helps to drive the AET in two main ways: 1) by incentivising farmers that they will receive recognition for their production practices in a way that is likely more feasible for them than formal third-party organic certification and 2) by teaching consumers that there are many ways of sustainable, agroecological food production that are not limited to being 100% certified organic, which include products that are often too expensive or hard to find for many consumers.

The switch to diets based on local food production often results from periods of scarcity that prevent trade, especially in, but not limited to, developing countries. Cuba is a paradigmatic example in this sense. Due to food shortages during the Special Period, the Cuban government and the Cuban National Association of Small Farmers promoted the Farmer to Farmer Agroecology Movement (MACAC, for its acronym in Spanish), which was quite successful in increasing the share of agricultural production performed with agroecological methods (Blay-Palmer et al., 2020). The MACAC programme is still functioning based on the peer-to-peer transmission of knowledge. Farmers organise themselves in groups, each with an average of 750 members, which exchange ideas both within and between groups through meetings, workshops, visits, etc. The emergence of the MACAC programme as a means to strengthen local food systems is an example of how a shift out of necessity, in this case, due to a crisis in the national food supply, can drive opportunities to rethink and build more sustainable and resilient food systems, particularly through the practice of agroecology. This is an especially contingent scenario in 2020, as the usual functioning of local food distribution, with particular regard to the reduced or unstable availability of imported products, is disrupted by the global COVID-19 pandemic (Kanter and Boza, 2020). Therefore, programmes such as the MACAC can both help promote local sustainable diets as well as an AET through peer-to-peer collaboration in making existing agricultural production systems more agroecological. Peer-to-peer learning programmes can even be adapted to social distancing scenarios through the use of communication technologies, but it is important to assess the level of digital literacy amongst potential users prior to doing so.

Another example of how the promotion of local sustainable diets can help drive an AET is evident through public policies in Brazil. The Brazilian Federal Food Acquisition Program and the National School Meal Program together mandate that a percentage of their budgets be used to acquire food from family farmers. Under the purchase with simultaneous donation system – the most common mechanism for the Brazilian National Food Supply Company (Conab, for its acronym in Portuguese) to purchase products from family farmers for these programmes – it is the farmers themselves that deliver their products to schools located in their territory. Therefore, the school menus in Brazil are adapted to available local foods as the culinary preparations are required to include them. In addition, farmers receive an overpayment of 30 % if their products are produced under agroecology practices. These policy examples from Brazil show that the public sector can use its purchasing power to enhance local sustainable food systems that also incentivise agroecological practices through local family farmers.

Another type of policy that can enhance the promotion of local sustainable diets based on agroecology at the national level is Food-Based Dietary Guidelines (FBDG). FBGD is a type of political document that specifies the nutritional principles for a population through a series of recommendations related to food, dietary patterns, and health. FBDG should consider the conditions of food supply, public health, and cultural preferences, among others. More than 90 countries worldwide have published their own FBDG, but only eight include sustainability (Herforth et al., 2019). The existing FBDG also rarely include recommendations on how or where foods should be produced. The 2014 Brazilian FBDG is an example of one that includes sustainability concepts as it recommends the consumption of natural or minimally processed foods, preferably organically or agroecologically produced, bought directly from the farmers themselves, if possible (Monteiro et al., 2015). FBDG similar to those established in Brazil, which consider how food production is practised and is context-sensitive, have the potential to orient national consumers towards local sustainable diets, ideally through recommendations of traditional and local foods. Thus, FBDG that include concepts around sustainability, including the importance of sustainable diets, have the potential to indirectly push policymakers and stakeholders to design-related public policies and programmes.

In addition to national policies and programmes, intergovernmental agencies also have a role to play in the promotion of local sustainable diets that together facilitate the transition towards global sustainable food systems. The FAO Draft Code for Sustainable Diets was developed between 2010 and 2012 by an expert working group in parallel to other existing food codes, such as the WHO International Code of Marketing Breast Milk Substitutes (Burlingame, 2019). The key ideas in the Draft Code for Sustainable Diets are: i) human health cannot be isolated from ecosystem health, ii) when ecosystems are capable of supporting sustainable diets, actions that promote other foods (e.g. ultra-processed foods and supplements) and related artificial sources of nutrients are inappropriate, and iii) every stakeholder has a role to play

(Burlingame, 2019). The Draft Code for Sustainable Diets is an excellent example of an initiative that has the potential to be a global standard; however, as of 2020, it has yet to be directly applied.

## 3 Conclusion

The trend in modern food systems is the ever-increasing distance between production and consumption. However, the scientific literature provides evidence that the concepts of local diets, as well as sustainable diets, share important dimensions with agroecological practices that have been incorporated into different programmes and policies worldwide. Local sustainable diets have characteristics that underpin, and thus, have the potential to facilitate the AET of modern food systems. We have presented several examples of public policies and community-level programmes that provide conditions for local sustainable diets with key elements that independently and together can drive the transition towards agroecological food systems. Although increasing in number, many actions that promote local sustainable diets are still barely put into practice or scaled up. Still, the Draft Code of Sustainable Diets offers a global approach to do so. To sum up, local sustainable diets provide essential drivers for the AET of modern food systems.

## Acknowledgements

This paper was funded by the Comisión Nacional de Investigación Científica y Tecnológica (CONICYT) – Fondo Nacional de Desarrollo Científico y Tecnológico (FONDECYT) (R.K., FONDECYT Initiation Research Project grant number 11170225). After this funding was granted, as of 01 January 2020, CONICYT (Chile) is now known as “la Agencia Nacional de Investigación y Desarrollo (ANID)”. The views in this paper represent only those of the authors.

### REFERENCES

Altieri MA (1995) Agroecology: The science of sustainable agriculture. 2nd Edition. Colorado: Westview Press, 433 p

Bergez JE, Audouin E, Therond O (2019) Agroecological transitions: From theory to practice in local participatory design. New York: Springer International Publishing, 335 p, doi:10.1007/978-3-030-01953-2

Bezner Kerr R, Rahmanian M, Owoputi I, Batello C (2019) Agroecology and nutrition: transformative possibilities and challenges. In: Burlingame B, Dernini S (eds) Sustainable diets: linking nutrition and food systems. Wallingford: CABI, Chapter 6, 53–63, doi:10.1079/9781786392848.0053

Blay-Palmer A, Conaré D, Meter K, Di Battista A, Johnston C (2020) Sustainable food systems assessment: lessons from global practice. Abingdon: Routledge, 263 p

Burlingame, B. (2019) Towards a code of conduct for sustainable diets. In: Burlingame B, Dernini S (eds) Sustainable diets: linking nutrition and food systems. Wallingford: CABI, Chapter 29, 268, doi:10.1079/97817863 92848.0268

FAO (2012) Sustainable diets and biodiversity: Directions and solutions for policy, research and action [online]. Rome: FAO, 307 p. Retrieved from < http://www.fao.org/3/a-i3004e.pdf> [at 9 Sept 2020]

FAO (2018) Sustainable food systems: Concept and framework [online]. Rome: FAO, 8 p. Retrieved from <http://www.fao.org/3/ca2079en/CA2079EN.pdf> [at 9 Sept 2020]

Herforth A, Arimond M, Álvarez-Sánchez C, Coates J, Christianson K, Muehlhoff E (2019) A global review of food-based dietary guidelines. Adv Nutr 10(4):590–605, doi:10.1093/advances/nmy130

Hunter D, Borelli T, Gee E (2020) Biodiversity, food and nutrition. A new agenda for sustainable food systems. Abingdon: Routledge, 296 p

Hvitsand C (2016) Community supported agriculture (CSA) as a transformational act – distinct values and multiple motivations among farmers and consumers. Agroecol Sustain Food Syst 40(4):333–351, doi:10.1080/21683565.2015.1136720

IFOAM (2014) Global comparative study on interactions between social processes and participatory guarantee systems. Bonn: IFOAM, 87 p

Kanter R, Boza S (2020) Strengthening local food systems in times of concomitant global crises: Reflections from Chile. Am J Public Health 110(7):971–973, doi:10.2105/AJPH.2020.30571

Köhler J, Geels FW, Kern F, Markard J, Onsongo E, Wieczorek A, Alkemade F, Avelino F, Bergek A, Boons F, Fünfschilling L, et al. (2019) An agenda for sustainability transitions research: State of the art and future directions. Environ Innov Soc Transit 31:1–32, doi:10.1016/j.eist.2019.01.004

Meybeck A, Gitz V (2017) Sustainable diets within sustainable food systems. Proc Nutr Soc 76(1):1–11, doi:10.1017/S0029665116000653

Monteiro CA, Cannon G, Moubarac JC, Bortoletto Martins AP, Adriano Martins C, Garzillo J, Silva Canella D, Garastri Baraldi L, Barciotte M, Da Costa Louzada ML, Bertazzi Levy R, et al. (2015) Dietary guidelines to nourish humanity and the planet in the twenty-first century. A blueprint from Brazil. Public Health Nutrition 18(13): 2311–2322, doi:10.1017/S1368980015002165

Ollivier G, Magda D, Mazé A, Plumecocq G, Lamine C (2018) Agroecological transitions: What can sustainability transition frameworks teach us? An ontological and empirical analysis. Ecol Soc 23(2):5, doi:10.5751/ES-09952-230205

Sonnino R (2016) The new geography of food security: exploring the potential of urban food strategies. Geogr J 182(2):190–200, doi:10.1111/geoj.12129

Volz P, Weckenbrock P, Cressot N, Parot J, Zoltán D (2016) Overview of community supported agriculture in Europe. Aubagne: European CSA Research Group, 133 p

Whitney E, Rolfes SR (2019) Understanding nutrition. 15th Edition. Boston: Cengage, 848 p

Willer H, Lernoud J (2019) The world of organic agriculture: statistics and emerging trends 2019. Frick: FiBL and IFOAM, 351 p

POSITION PAPER

# The BIOEAST vision of agroecology

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Received: April 3, 2020
Revised: June 2, 2020
Accepted: June 29, 2020


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KEYWORDS **agroecology, BIOEAST, Central Eastern Europe, sustainable agri-food systems, living labs, agroecological transition, new agricultural policy measures**

## 1 The decade of agroecological transition in the EU's agricultural policy

Creating more sustainable agricultural production systems drives the current European discussions on the new Common Agricultural Policy (CAP) and the new research and innovation framework programme, Horizon Europe 2021–27 (EC HE, 2019). The agriculture and food sector is traditionally one of the major fields that shape policies in the European Union (EU) as it generates approximately 44 million jobs, including 20 million people employed by the agricultural sector alone (Eurostat, 2018). The CAP alone constituted 37.2 % of the whole EU expenditure, while the societal challenge 'Food security, sustainable agriculture and forestry, marine maritime and inland water research and the bioeconomy' of the Horizon 2020 research framework programme allocated around 40 % of its total budget to agricultural research projects (EU REG, 2013; EC HE, 2015, 2017, 2020). Societal demand for these considerable funds to be utilised for transforming the current primary production and the entire food supply chain into a more sustainable system is stronger than ever.

To this end, the EU has become the frontrunner in setting ambitious objectives to achieve the United Nations' Sustainable Development Goals (SDGs) by 2030 and comply with the Paris Agreement via integrating economic, environmental and social sustainability measures into its policy. In December 2019, the European Commission adopted the European Green Deal, committing itself to zero net carbon emissions by 2050 and tackling environmental challenges in relation to agriculture, specifically mentioning the transformation of agriculture to climate-friendly, sustainable practices such as organic agriculture, agroecology, and agroforestry through its Farm to Fork Strategy (EC COM, 2019) and the new CAP. This ambition is also reflected in the Horizon Europe 2021–27 research and innovation framework programme, in which 'Cluster 6: Food, Bioeconomy, Natural Resources, Agriculture and Environment' (EC HE, 2019) prioritises the challenges, which current agricultural practices face, and puts the emphasis on more environmental-focused research targets that help the transition of agriculture toward sustainable production and food systems. The planned European Partnership on Agroecology, for which a preparatory call titled 'Accelerating farming systems' transition: agro-ecology living labs and research infrastructures' was already launched in 2019, explicitly addresses the importance of the agroecological approach and its multi-actor realisation (EC HE, 2019).

Assuming that necessary funding will be dedicated to the EU's ambitious objectives, it seems that the concept of agroecology and its means of implementation will have a central role within the new CAP and Horizon Europe to boost the regional implementation and upscaling of place-based solutions for sustainable production systems all over Europe. But how do we define and implement such an agroecological transition? The current paper aims to describe the position of the authors, who co-coordinate the Agroecology and Sustainable Yields Thematic Working Group of the BIOEAST[2]

[2] BIOEAST stands for the Central-Eastern European Initiative for Knowledge-based Agriculture, Aquaculture, and Forestry in the Bioeconomy.

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Initiative in collaboration with the Hungarian Ministry of Agriculture. The BIOEAST comprises 11 Central Eastern European (CEE) countries (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia) with the aim to define their common vision and strategic research and innovation agenda on agroecology.

## 2 The rise of the concept of agroecology – and how BIOEAST countries interpret it

Agroecology is not a new concept, even though it gained momentum in European policy only recently. The term 'agroecology' emerged in the late 1920s and was used to describe a scientific discipline that aimed to understand the ecological interlinkages between the different natural elements of an agricultural landscape (Altieri, 1999). Primarily, agroecology investigated the alternatives to chemical pesticides, such as biological pest management, or how to decrease the use of mineral fertilisers by understanding soil biology, while it also evaluated the economic impact of certain practices (Wezel et al., 2009; Altieri, 1999; Hatt et al., 2016). It is important to emphasise that agroecology as a science has been interdisciplinary right from the beginning, encompassing social and economic aspects beside natural sciences since it placed traditional agriculture practiced by smallholders and family farms at the centre of its investigations (Holt-Giménez and Altieri, 2013).

Agroecology started to outgrow its scientific borders from the 1980s onwards, when it evolved into a social (and later also a political) movement fostering a set of agroecological practices. As a movement, agroecology broadened its scope from the farm level and started to thematise social and economic aspects that address the inequalities in agriculture and the whole food system (food sovereignty, peasants' rights, access to genetic resources, the role of women in agriculture, etc.), involving a wide range of stakeholders in the value chain from farmers to consumers (Wezel et al., 2009; Gliessmann, 2018). Therefore, agroecology today incorporates the entire food system with all of its participants, integrating the above mentioned broad socio-economic dimensions, sustainable agricultural practices, and production systems that aim to reduce the impact of agriculture on the environment, such as organic farming, conservation agriculture, permaculture, etc. (Altieri, 1999; Wezel et al., 2009; Hatt et al., 2016; Gliessmann, 2018).

Due to its broad scope, local-specific and multi-stakeholder nature, agroecology has many definitions. Global intergovernmental organisations, such as the Food and Agriculture Organization of the United Nations (FAO, 2018) or the High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2019), regard agroecology as a tool to achieve the SGDs. The social movement side of agroecology represented by Agroecology Europe, has also formulated its own definition, which is based on the principles set by FAO and HLPE (see website Agroecology Europe, 2020).

Although the international concepts of agroecology are very broad and diverse and there is also no official definition at the EU level, agroecology as a term is being used more and more frequently in the European agricultural policy debate. It is mainly regarded as a promising approach comprising sustainable farming practices where ecosystem services are maintained and sustainably managed to maximise crop growth and animal welfare through appropriate resource management. As such, "agroecology most recently has become an umbrella concept of European agricultural and food policy which aims to trigger the transition to a more sustainable agri-food system" (EC COM, 2019; EC HE, 2019). In line with this interpretation, the CEE countries realised the need to translate the notion of agroecology to their specific economic, environmental, and social contexts in order to make sure that future European policies on agroecology are fit for purpose in this macro-region.

The BIOEAST countries emphasise their joint commitment in achieving the EU's aspiration toward more sustainable agriculture, and aim to formulate a joint strategic research and innovation agenda (SRIA) for working towards sustainable, knowledge-based agriculture, aquaculture, and forestry in the CEE macro-region by 2021. The BIOEAST SRIA, including its agroecology chapter, is also meant to provide recommendations for the European Commission on the BIOEAST countries' research needs that may be taken into account when designing the new Horizon Europe work programme.

Taking into account that in the Central Eastern European countries national policies traditionally strongly focus on achieving economic growth and closing up to Western European economic status, and that this may happen to the detriment of sustainability measures, it is evident that the BIOEAST SRIA needs to overcome the currently practiced subjugation of agriculture to short-term economic benefits and societal trade-offs. The SRIA needs to set a new vision on "agroecology as a sustainable growth model", specific to the unique economic, social, environmental, and cultural challenges and characteristics of the CEE macro-region. It thus needs to address the increasing socio-economic and environmental externalities that are deeply rooted in the current agricultural treadmill (Crews et al., 2018). In the following, we describe where the BIOEAST vision on agroecology currently stands in the ongoing process of its co-creation.

## 3 What is specific about the CEE region?

Agroecology represents a promising approach not just because it can develop sustainable practices for agriculture but also aims to manage complex global problems on the local level, therefore finding different solutions to a given problem based on regional characteristics. Regarding environmental challenges, the negative impacts that resource and chemical-intensive agriculture[3] poses on the environment and human health (soil depletion and erosion, surface and groundwater contamination by nitrate leaching, biodiversity loss, high levels of greenhouse gas emissions, water scarcity,

[3] Of all farms in the EU (10.5 million in total), only 2.9 % (dominantly large-scale enterprises) accounted for the majority (55.6 %) of the EU's total agricultural economic output, whereas small-scale farms account for 67.6 % of all farms in the EU. Large farms use approximately 52 % of all agricultural land in the EU. Operating a large farm often results in the decline of agricultural diversity and the rise of input-intensive practices (Eurostat, 2016).

etc.) (IPCC, 2019; IAASTD, 2009) in the CEE region are similar to other parts of Europe. To face these challenges, the CEE countries, as all other countries of Europe, need to safeguard their natural resources and ecosystem-services by transforming their agricultural production systems to more sustainable practices. However, in order to successfully achieve this, the CEE countries must address the specific challenges they face from an agricultural economics and socio-cultural perspective. These challenges are very much different from those of the EU-15[4] countries, and overcoming them requires specific efforts. In the following, we provide an insight into the most important differences.

The primary production sector is the motor of Europe's bioeconomy. Agriculture and the food industry provide approximately 63 % of the EU's total employment (agriculture 19 %, food sector 44 %), which constitutes 76 % of the total turnover of the EU's bioeconomy (agriculture 54 %, food sector 22 %) (JRC, 2018). The analysis of the relationship between employment and turnover only for the CEE countries, where agriculture is historically an important economic sector, shows that these countries account for about 48 % of the EU's employment in agriculture, but their share of the European agricultural turnover is only 16 % (NOVA, 2018). This disproportion is mostly related to three tendencies observed in the CEE countries:

1) The comparatively low agricultural productivity in the region, which is 39.6 % of the EU average (BIOEAST, 2018). This is most apparent in the so-called yield gap in cereal production between the EU-15 and CEE countries. EU-15 produce an average of 6.5 t/ha, while the average cereal yield in the CEE region is 5.2 t/ha (ECSTAT, 2019). Although it may very well be so that the 6.5 t/ha yield in EU-15 is too high, given that this production is only possible by using practices that are unsustainable in the long run. Currently a plateauing or declining in wheat yields in the EU-15 is observed and there is interest to keep this level whilst introducing more sustainable practices (Ray et al., 2012). On the other hand Salmon et al. (2017) claim that yields in the CEE region are projected to increase significantly (15 to 50 %) by 2026, especially those of cereals. An economic growth opportunity that CEE countries are keen not to miss, however, needs to be carefully analysed and addressed so that environmental and social dimensions of agriculture are not suppressed for the sake of economic growth.

2) The labour productivity in agriculture is 20 % lower in the CEE region than the EU average, which can be traced back to lower technological, infrastructural, and organisational development of the region (Eurostat, 2019). At the same time, this might also mean that CEE countries use less herbicides and heavy machinery and have a less uniform agricultural landscape than the EU-15, which is beneficial to ecosystem services such as pollination and pest control. Lower application rates of fertilisers (mineral as well as manure) allow lower levels of surface water eutrophication and better-conserved marine zones, etc. However, here again, we are confronted with setting EU-15 as an economic role model, while acknowledging the need for alternative solutions to avoid negative environmental externalities.

3) The difference between EU-15 and CEE countries is also apparent in the below-average gross hourly earnings in the agricultural sector of the CEE countries: 3 to 6 EUR/hour in the CEE compared to the 16 EUR/hour EU average (ICEPS, 2013). These figures should be normalised using the overall level of earning between countries or analysed in more detail by looking at the earnings within different sectors of agriculture in both regions. However, even without a more detailed comparison, the broad figures themselves indicate why agriculture in the CEE has such a disproportionately low share in the EU agricultural turnover and thus, from a solely economic perspective, relatively low importance.

Overall, we concur with Horváth et al. (2019) that although the EU-15 countries have reached a high technological development and efficiency in agriculture resulting in high productivity, at the same time, the environmental resources have become highly depleted due to unsustainable practices in these countries. While productivity in the CEE region is lower than the EU average mainly due to (on average) less intensive production practices and poor sectoral organisation, the region is more abundant in natural resources, such as natural habitats and biodiversity. However, even though the negative impacts of over-intensive agriculture are widely known, the economic status of EU-15 remains a role model for the CEE countries, and politically there is a keen interest to close up to the EU-15 productivity level.

Therefore, the following question emerges: is it possible to increase the productivity of agriculture in the CEE region while phasing out the unsustainable use of natural resources? Should BIOEAST set the closure of the yield gap as a target of the agroecological transition? Since the concept and practical solutions of organic agriculture are very much in line with those of agroecology, the International Federation of Organic Agriculture Movements (IFOAM) highlights organic agriculture as a model of agroecological farming (IFOAM, 2019). Organic agriculture shows positive results in terms of some environmental and social metrics such as increased local agrobiodiversity, better livelihood for farmers, higher employment of farmers, or better cooperation among farmers (Reganold and Wachter, 2016). However, it is important to point out that its yield performance compared to conventional practices varies within a wide range (high differences between cereal or horticultural crops) and its overall productivity is highly context-dependent (Seufert and Ramankutty, 2017). We also know that the more intensive an agricultural system is, the exponentially more input resources are needed to achieve the same amount of productivity growth than in case of less intensive production systems (Tittonell et al., 2016). In view of such results, it seems challenging to develop new, truly agroecological practices that are able to produce even higher yields than our current input-based, intensive production systems while not compromising environmental and social sustainability. However, high hopes are put into artificial intelligence-based decision-making systems and

[4] EU-15 stands for the 15 "old" member states of the European Union: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

precision agriculture techniques that may become new tools for answering this challenge (Bilali and Allahyari, 2018).

Whether a technology-focused agroecological approach lives up to current "sustainable intensification" expectations or not, the agroecological transition needs to apply new, environmentally friendly production methods that have the potential to stabilise yields also under adverse climatic conditions while maintaining or increasing farmer income, e.g. through innovative policy measures that favour the agricultural production of public goods.

Reaching the EU average wages in CEE agriculture will be a prominent issue in the coming years that also relates to the long-term development of rural communities since rural areas are more densely populated in the CEE region than in EU-15, and agriculture in rural areas generates 25 % of all jobs in the CEE region (BIOEAST, 2018). More importantly, the adaptive capacity and preparedness of rural communities to climate change is low, yet according to projections climate change will hit the CEE region disproportionately hard (EEA, 2019). Key challenges of agriculture related to climate change appear in form of extreme hot periods, uneven distribution and amount of precipitation, water shortages such as decrease of surface and ground water levels and reduction of soil moisture. Regardless of climate change, there is a need for technical and management improvement. To mention one example, as the exposure of soils to compaction is higher in the CEE region, agricultural productivity, which is already low, can rapidly decline (Lavalle et al., 2009; EEA, 2019).
Also, adaptive capacity can be increased through applied research and innovation. This activity has, however, been rather modest in the CEE area. According to Pokrivcak et al. (2019), this can be attributed to the differences in farm structure between the CEE countries and EU-15, such as the lower number of technology-intensive farms, and the low cooperation between producers of the CEE region. This may have resulted in a comparative disadvantage for the CEE countries to apply for research and innovation funds as they could not benefit from funds that are intrinsically tailored to larger, technology-ready operations. However, this argument needs to be further supported by a more detailed analysis of farm structure specificities among the CEE countries as their characteristics are far from homogeneous within the macro-region (see Guiomar et al., 2018).

Considering the region-specific economic and socio-cultural challenges of agriculture shared in the CEE countries, setting joint research priorities for an agroecological transition is even more important to ensure tailor-made solutions instead of general measures that may in fact prove counter-productive for the region.

## 4 Applying the CEE vision of agroecology

The CEE vision of agroecology is aimed to reach high levels of technological, knowledge, research, and innovation outputs by transforming the region's agriculture and food system using the full potential of sustainable practices based on agroecological principles. To achieve this vision, the CEE countries of the BIOEAST initiative are ready to establish and operate a network of agroecological living laboratories (or living labs) as an effective tool to realise this focus (BIOEAST TOR, 2019). The expression 'living laboratory' defines open innovation systems or environments that directly integrate all stakeholders of a given value chain in the development process to find solution to a specific problem (Feurstein et al., 2008). By translating the concept of living labs to the agricultural and food sector, the CEE countries aim to support the creation of living labs that can tackle the complex economic, environmental, and social challenges related to the agriculture and food sectors of the region by finding innovative, local-specific, and practical solutions through agroecological approaches.

The network of living labs, collecting and sharing good practices in order to encourage agricultural innovations and agroecological transition is also foreseen in the Partnership on Agroecology within Horizon Europe 2021-27. As a preparation for the Partnership, the following steps have been determined by the BIOEAST countries:

1. To study and synthetise existing national agricultural research and innovation strategies and collect good agroecological policy examples from the macro-region.
2. To set up a network of relevant stakeholders (embracing small and medium enterprises, large companies, farmers, advisors, researchers, consumers, public and civil society organisations) of the BIOEAST countries to collect and discuss practical experiences with agroecological transition pathways.
3. To stimulate discourse on agroecological sector development in the CEE region in light of the diverging visions on fostering competitiveness through closing the yield gap vs achieving sustainable income with enhancing yield resilience.
4. To implement policy pilots and seek financing resources in the CEE region and the EU for creating an enabling environment for agroecological living laboratories and for testing place-based agroecological innovations.
5. To contribute to the programming of the national Strategic Plans of the Common Agricultural Policy in order to guarantee policy consistency throughout the macro-region.

Moreover, the BIOEAST thematic working group on Agroecology and Sustainable Yields is represented by its coordinators in the Horizon 2020 preparatory action Strengthening the European agro-ecological research and innovation ecosystem, which aims to develop the framework for a European network of agroecological living labs and research infrastructures (EC, 2019). Within this keystone project of the EU's agroecological transition, we coordinate stakeholder engagement and the creation of a pilot network of agroecological living labs, where this approach may be tested and developed further under real-life conditions.

## 5 Conclusion

This position paper is aimed to present the diverging interpretations of agroecology within the international agricultural and food policy debate with a special focus on the EU and the Central Eastern European countries. More importantly, the paper emphasises the relevance of creating a joint vision on agroecology and a Strategic Research and Innovation Agenda specific to the unique economic, environmental, and social aspects in the CEE region. However, this vision needs a broad political willingness to be implemented in practice across the macro-region, which raises several questions mainly concerning the future economic output of CEE agriculture and the financial support allocated or available to the BIOEAST SRIA objectives. Still, the vision of agroecology in the BIOEAST countries points out that for the CEE region agroecology represents an opportunity to create innovative, regional solutions for an environmentally but also economically and socially sustainable agricultural system. However, this can be achieved only if the fragmentation of agricultural policies is avoided and a system-based approach, which is based on strong socio-economic arguments, is implemented.

## REFERENCES


Agroecology Europe (2020) Website. Retrieved from <https://www.agroecology-europe.org/> [at 20 Jan 2020]

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ 74(1):19–31, doi:10.1016/S0167-8809(99)00028-6

BIOEAST (2018) BIOEAST vision paper [online]. Retrieved from <https://bioeast.eu/download/bioeast_vision_paper_23022018/> [at 20 Oct 2019]

BIOEAST TOR (2019) Terms of References – internal working document of the Agroecology and Sustainable Yields Thematic Working Group

Crews TE, Caron W, Olsson L (2018) Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. Global Sustain 1 (e11): 1–18, doi:10.1017/sus.2018.11

EC, European Commission (2019) Work programme: Strengthening the European agro-ecological research and innovation ecosystem, Call ID: FNR-01-2020 [online]. Retrieved from <https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/fnr-01-2020> [at 28 May 2020]

EC CAP (2019) Common agricultural policy: Key graphs and figures [online]. Retrieved from <https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/cap-expenditure-graph1_en.pdf> [at 10 Sept 2020]

EC COM (2019) The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions [online]. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN> [at 10 Sept 2020]

EC HE (2015) Horizon 2020. Work Programme 2014–2015: Food Security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy. European Commission Decision C (2015) 2453 of 17 April 2015 [online]. Retrieved from <https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-food_en.pdf> [at 19 Sept 2020]

EC HE (2017) Horizon 2020. Work Programme 2016–2017: Food Security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy. European Commission Decision C (2017) 2468 of 24 April 2017 [online]. Retrieved from <https://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-food_en.pdf> [at 19 Sept 2020]

EC HE (2019) Orientations towards the first strategic plan for Horizon Europe [online]. Retrieved from <https://ec.europa.eu/info/sites/info/files/research_and_innovation/strategy_on_research_and_innovation/documents/ec_rtd_he-orientations-towards-strategic-plan_102019.pdf> [at 10 Sept 2020]

EC HE (2020) Horizon 2020. Work Programme 2018–2020: Food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy. European Commission Decision C(2020)6320 of 17 September 2020 [online]. Retrieved from <https://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-food_en.pdf> [at 19 Sept 2020]

EC STAT (2019) Cereals statistics overview [online]. Retrieved from <https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/overviews/market-observatories/crops/cereals-statistics_en> [at 25 Jan 2020]

EEA, European Environment Agency (2019) Climate change adaptation in the agriculture sector in Europe. Luxembourg: Publications Office of the European Union, 112 p, EEA Report No. 04/2019, doi:10.2800/537176

EU REG (2013) Regulation (EU) No 1291/2013 of the European Parliament and of the Council of 11 December 2013 establishing Horizon 2020 – the Framework Programme for Research and Innovation (2014–2020) and repealing Decision No 1982/2006/EC [online]. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02013R1291-20150704> [at 19 Sept 2020]

Eurostat (2016) Farms and farmland in the European Union – statistics [online]. Retrieved from <https://ec.europa.eu/eurostat/statistics-explained/index.php/Farms_and_farmland_in_the_European_Union_-_statistics> [at 4 May 2020]

Eurostat (2018) Agriculture, forestry and fishery statistics – 2018 edition. Luxembourg: Publications Office of the European Union, doi:10.2785/340432

Eurostat (2019) Performance of the agricultural sector. Retrieved from <https://ec.europa.eu/eurostat/statistics-explained/index.php/Performance_of_the_agricultural_sector#Agricultural_labour_productivity> [at 20 Jan 2020]

Feurstein K, Hesmer A, Hribernik KA, Thoben KD, Schumacher J (2008) Living labs: a new development strategy. In: Schumacher J, Niitamo VP (eds) European living labs – a new approach for human centric regional innovation. Berlin: Wissenschaftlicher Verlag, 1–14

FAO (2018) The 10 elements of agroecology. Guiding the transition to sustainable food and agricultural systems. Rome: FAO, 15 p. Retrieved from <http://www.fao.org/3/i9037en/I9037EN.pdf> [at 20 Dec 2019]

Gliessman S (2018) Defining agroecology. Agroeol Sust Food 42(6):599–600, doi:10.1080/21683565.2018.1432329

Guiomar N, Godinho S, Pinto-Correia T, Almeida M, Bartolini F, Bezák P, Biró M, Bjørkhaug H, Bojnec Š, Brunori G, Corazzin M, et al. (2018) Typology and distribution of small farms in Europe: Towards a better picture. Land Use Policy 75:784–798, doi:10.1016/j.landusepol.2018.04.012

Hatt S, Artru S, Brédart D, Lassois L, Francis F, Haubruge É, Garré S, Stassart PM, Dufrêne M, Monty A, Boeraeve F (2016) Towards sustainable food systems: the concept of agroecology and how it questions current research practices. A review. Biotechnol Agron Soc Environ 20(S1):215–224, doi:10.25518/1780-4507.12997

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]

Holt-Giménez E, Altieri MA (2013) Agroecology, food sovereignty, and the new green revolution. Agroecol Sustain Food Syst 37(1):90–102, doi:10.1080/10440046.2012.716388

Horváth B, Bahna M, Fogarassy C (2019) The ecological criteria of circular growth and the rebound risk of closed loops. Sustainability 11(10):2961, doi:10.3390/su11102961

IAASTD, International assessment of agricultural knowledge science and technology for development (2009) Agriculture at a crossroads – synthesis report. Washington: Island Press, 36 p

ICEPS (2013) Employment in European agriculture: labour costs and working time flexibility in agriculture [online]. Köln: Institut der deutschen Wirtschaft, 30 p, Project report EA(14)3559:3. Retrieved from <https://copa-cogeca.eu/img/user/files/KAUNAS2013/EA(14)3559EN3.pdf> [at 10 Sept 2020]

IFOAM (2019) Organic and agroecology: working to transform our food system [online]. Bonn: IFOAM EU, 13 p. Retrieved from <https://www.organicseurope.bio/content/uploads/2020/06/ifoameu_position_paper_agroecology.pdf?> [at 10 Sept 2020]

IPCC, Intergovernmental Panel on Climate Change (2019) Climate change and land. An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Retrieved from <https://www.ipcc.ch/srccl/> [at 10 Sept 2020]

JRC, Joint Research Center (2018) Socio-economic insights into the bioeconomy in BIOEAST countries – research brief. Brussels: European Commission. Retrieved from <https://ec.europa.eu/knowledge4policy/sites/know4pol/files/2018_socio_economis_insights_jrc_researchbrief_bioeast.pdf> [at 20 Dec 2019]

Lavalle C, Micale F, Houston TD, Camia A, Hiederer R, Lazar C, Conte C, Amatulli G, Genovese G (2009) Climate change in Europe. 3. Impact on agriculture and forestry. A review. Agron Sustain Dev 29:433–446, doi:10.1051/agro/2008068

NOVA (2018) State of play of central and eastern europe's bioeconomies. Huerth: Nova Institute for Ecology and Innovation, 37 p. Retrieved from <http://www.scar-swg-sbgb.eu/lw_resource/datapool/_items/item_33/state_of_play_central_and_eastern_eu_bioeconomies.pdf> [at 13 Jan 2020]

Pokrivcak J, Ciaian P, Drabik D (2019) Perspectives of Central and Eastern European countries on research and innovation in the new CAP. EuroChoices 18(1):26–32, doi:10.1111/1746-692X.12220

Ray DK, Ramankutty N, Mueller ND, West PC, Foley JA (2012) Recent patterns of crop yield growth and stagnation. Nat Commun 3:1292, doi:10.1038/ncomms2296

Reganold J.P, Wachter JM (2016) Organic agriculture in the twenty-first century. Nat Plants 2:15221, doi:10.1038/nplants.2015.221

Salamon P, Banse M, Barreiro-Hurlé J, Chaloupka O, Donnellan T, Erjavec E, Fellmann T, Hanrahan K, Hass M, Jongeneel R (2017) Unveiling diversity in agricultural markets projections: from EU to member states. A medium-term outlook with the AGMEMOD model. Luxembourg: Publications Office of the European Union, 90 p, JRC Technical Reports 29025 EUR, doi:10.2760/363389

Seufert V, Ramankutty N (2017) Many shades of grey – The context-dependent performance of organic agriculture. Sci Adv 3(3): e1602638, doi:10.1126/sciadv.1602638

Tittonell P, Klerkx L, Baudron F, Félix GF, Ruggia A, Apeldoorn D, Dogliotti S, Mapfumo P, Rossing WAH (2016) Ecological intensification: local innovation to address global challenges. In: Lichtfouse E (ed) Sustainable agriculture reviews, Cham: Springer International Publishing, 1–34, doi:10.1007/978-3-319-26777-7_1

Wezel A, Bellon S, Doré T, Francis C, Vallod D, 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

 

POSITION PAPER

# Agroecology empowers a new, solution-oriented dialogue

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Received: April 14, 2020
Revised: July 7, 2020
Accepted: August 12, 2020


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KEYWORDS **agroecology, productivity, organic farming, innovation, dialogue**

## 1 Introduction

The global production of food comes at the expense of non-commodity ecosystem services, eco-stability, and human wellbeing; consequently, it threatens the stability of the planet (Steffen et al., 2015). An ongoing growth of the world population combined with the increasing wealth of low and mid-income countries, which is accompanied by higher protein consumption (especially of meat), threatens to escalate the overexploitation of natural resources, leading to higher greenhouse gas emissions, deforestation, and land degradation (FAO, 2017).

While scientists and politicians broadly share this analysis and acknowledge the urgent need for action, there are several different narratives as to where solutions should be sought (see *Figure 1*). Of these, the prevailing one, is sustainable intensification. While the term dates back to 1997 (Pretty, 1997), today this narrative finds broad support, is promoted by FAO, and is widely employed by the international research and development community as well as businesses driving industrial agriculture (Tittonell, 2014; Garnett et al., 2013). Sustainable intensification is characterised by a drive towards a greater output of food and feed per agricultural input, including land. It also causes less pollution and other negative externalities per output and is therefore said to be more (eco)efficient. It leaves some room for nature conservation and high-natural-value areas because most of the agricultural surface is highly productive. Productive land and areas serving the common good are segregated. The contrasting narrative is ecological intensification. "While sustainable intensification is generally loosely defined, so that almost any model or technology can be labeled under it, ecological intensification proposes landscape approaches that make smart use of the natural functionalities that ecosystems offer. The aim is to design multifunctional agroecosystems that are both sustained by nature and sustainable in their nature." (Tittonell, 2014). Ecological intensification relies on ecosystem functions like soil fertility and biodiversity, whereas off-farm inputs become less important. By design, maximum yields are unlikely to be reached. Consequently, it is important to reduce food waste and meat consumption accordingly (Schader et al., 2015; Müller et al., 2017). The contrast between these two narratives can be summarised as efficiently managed productivity versus moderation or sufficiency in nutrition to reduce the need for further increases in agriculture productivity. In practical implementation, these two strategies mean a technologically improved conventional or integrated agriculture on the one hand and organic farming on the other (Reganold and Wachter, 2016). But this either-or is more clearly separated in theory than in practice. Often, diversified or extensive conventional farms are as sustainable as very intensive organic

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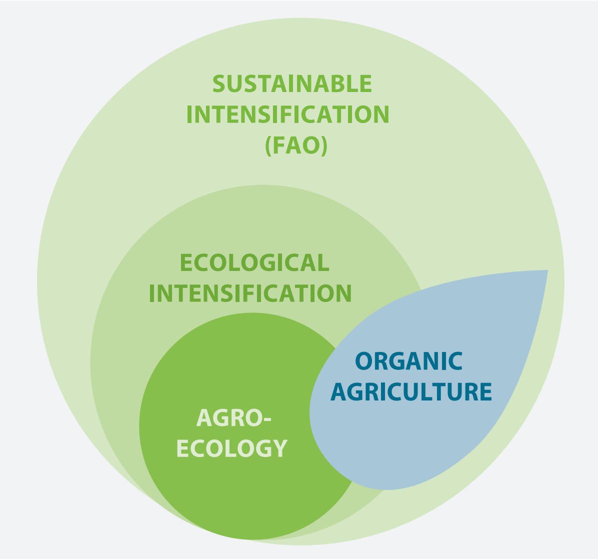


FIGURE 1
Different concepts of sustainable food production. The concepts differ in terms of the relationship between productivity and ecological footprint. The size of the circle symbolises the productivity and the intensity of the green colour the excellence in ecology and environment. Organic agriculture extends across all three concepts, depending on the production sector and the intensity of production.

sectors of production or whole farms and sometimes even more so (Sanders and Heß, 2019; Haupt et al., 2018). Could the concept of agroecology help to build bridges between these perspectives and facilitate solution-oriented dialogues?

## 2 Agroecology: from science to practice

Regional and international conferences on agroecology held by FAO from 2014 to 2017 led to the identification of ten principles characterising agricultural and food systems as agroecological (FAO, 2018). These principles describe the common mechanisms of such systems as diversity, synergies, efficiency, resilience, recycling, as well as co-creation and sharing of knowledge. Furthermore, the principles highlight human and social values, culture, and food traditions. Responsible governance, as well as circular and solidarity-oriented economy, are crucial as they produce the enabling environment, necessary for agroecology to thrive. In its latest and 14th report, the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE) complemented the definition of agroecology with its 13 principles (HLPE, 2019), of which some were more technical and production-oriented, although they all point into the same direction.

The evolution of the term 'agroecology' encompasses a drastic shift from its use in scientific research to ecological farm practice and on to describe a farmer-led social movement. Agroecology emerged in the early 20th century when researchers studying the interaction between crops and the environment started applying a scientific understanding of ecology to agriculture (Tischler, 1965). Altieri went a step further when he used scientific findings to design sustainable cropping systems (1995). He contextualised productivity related to regions, ecological zones, landscapes, and the socio-economic sphere and adapted agricultural practices by listening to and involving farmers (HLPE, 2019). Hence, the key aspects of agroecological research include participatory knowledge development, on-farm studies, and holistic research approaches that consider wide-ranging social and economic factors (TWN and SOCLA, 2015).

This new integrative scientific approach has led to a multitude of developments in farm practices and techniques. Agroecological farms apply the best sustainable practice, such as diverse crop rotations, mixed crop-livestock systems, polycultures, inter-, cover-, and mixed cropping, natural or semi-natural habitats and corridors, and local marketing and value creation. Further important aspects are local breeding programmes and re-using resources from local agroecosystems (Gliessmann, 2006). However, agroecological farming is best understood as a guiding principle and a practical approach that develops over time rather than as prescribing a static set of practices. Unlike the related concept of organic agriculture, it is explicitly uncodified and unrestrictive. Crucially, agroecological farming emerged from a participatory process and often through the active cooperation of enthusiastic producers, processors, and consumers, who pursue well-formed goals within their own spheres of responsibility, without an overly heavy focus on inspection and certification. At the same time, agroecology does not lose sight of the importance of this for organic producers who want to enter remote and anonymous market places. An instructive example is provided by the state of Sikkim, India, which has successfully transitioned towards the application of 100 % organic farming while becoming a major exporter of fruits, flowers, spices, and vegetables (Kumar et al., 2018). Successes like this bear the agroecological principles devised by FAO and HLPE, which depend on an enabling socio-economic environment, a fair and participatory political process (including financial support from the state government), a focus on crops with market potential for export, and the recognition of group certification (Bharucha et al., 2020; Meek and Anderson, 2020).

At its best, agroecology can take advantage of a multiplicity of solutions, combining technology and traditional knowledge to improve inputs and outputs of the agricultural process. Agroecological systems include organic farming (Niggli, 2015), permaculture, low external input sustainable agriculture (LEISA), and agroforestry (Armengot et al., 2016). All those systems fall under the ten elements of the FAO framework as well as the thirteen principles consolidated by the HLPE, albeit with different weighting and target achievement. Some of their techniques are not compatible with organic standards, like combined fertilisation with organic manure and synthetic fertilisers or the spraying of synthetic herbicides and pesticides in exceptional cases, which is decided on by the farmer (such as a risk of a severe harvest loss that threatens the economic sustainability of the farm).

Peasant farmer groups, like La Via Campesina, have pressed for further changes to the concept of agroecology.

Their emphasis on social, cultural, and political principles has transformed the idea of agroecology into a strong global movement against globalisation and free trade and for food sovereignty (La Via Campesina, 2018; Wezel et al., 2009). Strong political commitments and the horizontal integration of civil society organisations provide an excellent incentive for farmers not to fall back to old, unsustainable practices (Tittonell, 2014; Rosset et al., 2011). Indeed, building social capital and new modes for the co-creation of knowledge are vital prerequisites for a successful scaling-up of agro-ecological farm management practices (Pretty et al., 2018). Many such farmer organisations and social movements now use the concept of agroecology as an overarching political framework to secure their rights and safeguard locally adapted small-scale farms (HLPE, 2019).

Meanwhile, selected agroecological practices are being applied to industrial agriculture in farming systems, such as low input agriculture, precision farming, integrated pest management[3] and integrated production, farms optimised by life cycle assessment, and conservation tillage. These all fall under the concept of sustainable intensification. Many of these management practices have been fostered by agri-environmental measures taken by governments. For example, in 2013, the European Commission established a policy of 'greening' and since then has required a few agroecological practices for all direct payments to farmers (EC, 2013). However, these requirements are low, and the measures have proven ineffective in achieving sustainability targets.

## 3 The greatest obstacles to the upscaling of agroecology

Recently, scientists assessed sustainable intensification initiatives worldwide and estimated that 29 % of all farms are practicing some form of redesigned systems for sustainable intensification (including agro-ecological systems) on 9 % of global agricultural land (Pretty et al., 2018). They concluded that the adoption of sustainable systems might be on the brink of effecting a global transformation (Parmentier, 2014). Organic farming, on the other hand, has already reached this point in many European countries and regions and has become mainstream in the Alpine regions of Austria, Germany, and Switzerland, where 60 % of all farms are certified organic and organic milk has become the standard. Producers have thus responded to the strong demand for such products. Worldwide, however, the share is still marginal at 2.2 % of the agricultural area (Willer et al., 2020).

The biggest challenge is certainly the inherent contradiction between productivity and excellence in environmental standards, as well as the associated trade-off between the economic and the ecological dimensions of sustainability. This creates great uncertainty as to whether both agroecological and organic farming systems can contribute to food security (Seufert and Ramankutty, 2017). However, the former UN Special Rapporteur on the Right to Food stated that productivity could be doubled in twenty African countries if agroecological methods were adopted (De Schutter, 2010). But this conclusion mainly applies to subsistence farming, where agroecological practices – actually, as mentioned above, the best agronomic practice – represent an important first step towards intensification. In any case, this contradiction will have to be resolved since intensive agricultural production depends on high utilisation of resources, which will become scarce in the future (FAO, 2017). In contrast, agroecology strives to minimise reliance on external inputs as far as possible. Many of the techniques of organic agriculture and low-input practices have shown that this is feasible. Mäder et al. (2002) and Oel et al. (2003) demonstrated that close correlation between organic, low-input farming systems and higher soil biomass, higher AMF mycorrhiza diversity, and higher root colonialisation lead to higher phosphorous use efficiency. Moreover, they pointed out that organic fertilisers, reduced soil tillage, reduced pesticide use, diverse crop rotations, mixed cropping, as well as green manure – all characteristic of agroecological practice – were the most effective available techniques.

Yet, it remains uncertain whether resolving the trade-off is possible without fundamentally changing the existing capitalist socio-economic system (Jackson and Victor, 2019; Seidl and Zahrnt, 2019). The economic paradigm that underlies most economical and financial systems originate from the Chicago School. These neoclassical economic models are not socially embedded in the sense that they neglect societal and environmental factors such as institutions, natural resources, and energy. They promote a form of globalisation that amplifies transportation activities, increases global competition, and reduces prices of food commodities. And finally, these economic models are infused with an optimistic belief that technological progress coupled with market mechanisms has the capacity to overcome all limitations of natural systems. A fundamental change would be a herculean (if not demiurgical) task if it were even possible or desirable. In any case, the resulting reduction of economic growth would, in turn, entail a trade-off against the social dimension of sustainability (as it reduces prosperity) and therefore would be a source of conflicts.

The question of the productivity of cultivation systems is a very complex one. For many years, it has been discussed in a markedly inconsistent manner. Those involved in the debate often only draw attention to partial aspects of the problem, argue within different time horizons, and ignore facts and figures that do not support their own position. The predominant opinion is that it is primarily the strongly growing demand for food that drives agricultural productivity (Meemken and Qaim, 2018) and that this productivity has to be upheld. In fact, nitrogen fertilisers, crop protection, and irrigation together with high yielding varieties have massively increased yields over the last 60 years. But, critical voices have asked, at what cost does this come? It is also certainly true that the long-term productivity of agriculture is threatened by the depletion of natural resources such as fertile soils, water reserves, biodiversity, and landscape habitats.

[3] The term 'integrated pest management' for us refers to a strict and binding implementation of a combination of biological, biotechnical, plant breeding, and cultivation measures in order to reduce the application of chemical plant protection products to a bare minimum (Niggli et al., 2020.

The main arguments against the over-emphasis on the future yield deficit that could be caused by agro-ecological cultivation methods are right to highlight other factors, such as the poor management of world harvests, poverty, and conflicts. Nevertheless, the FAO expects a gap of 7,400 trillion calories by 2050, which would call for an increase of production by 56 % (Alexandratos and Bruinsma, 2012). According to current patterns of land use, such an increase would then require 593 million hectares of additional agricultural land, an expansion of both cropland and permanent grassland. For a scenario of 100 % conversion to organic farming, the global agricultural land may further expand by 33 % (Müller et al., 2017). Additional productive land would have to be gained through deforestation, drainage of high moors, and conversion of grassland to arable land. The negative impact on biodiversity and climate change in this scenario would be dramatic (Burney et al., 2010). On top of the FAO basic scenario for 2050, Müller et al. (2017) and Schader et al. (2015) modelled scenarios with a rising percentage of organic land (0 to 100 %), with changing meat consumption, with more or less successful food wastage reductions, and with three global warming impacts (no impact on yield, medium, and strong impact). Their simple conclusion was that eating less grain-fed meat and reducing food waste would most effectively mitigate this productivity gap and is likely to represent the only realistic exit strategy in the long run.

But here we should be cautious. A fairly likely scenario is that this kind of change in consumer behaviour (the sufficiency narrative) will take several generations and that prosperity in emerging countries will have exactly the opposite effect. For the time being, meat consumption and food wastage will continue to grow, the latter triggered by a trend towards convenience food in the growing middle class and the dramatic increase in disruptive societal crises such as rural exodus, conflicts, or pandemics. Hence, it seems likely that society will continue to be caught in the productivity trap. How do we meet this pressing challenge?

## 4 The way forward

Against this backdrop, it is evident that agroecology in science and education has a pivotal role to play. However, we are still far from achieving this state of affairs. Science might find better and more sustainable solutions, but this relies on them being conducted in the context of a strongly diversified production system based on low external input, high internal activation of resources, and high transformative efficiency. This type of research also requires meaningful cooperation between disciplines. This means more than multi- or interdisciplinarity; in the best-case scenario, boundaries between the disciplines dissolve and disciplines merge into a common working framework also known as design thinking or even postdisciplinarity (Brown, 2009). This will lead to a better understanding of agricultural practice and local production conditions but requires different working procedures. The problem here is that in mixed research consortia, individual competences often drift apart and results in more competition instead of cooperation. Yet, new digital communication possibilities may offer better opportunities to create data jointly and to work with several teams on method development. One could label this new approach to collaboration 'swarm intelligence' as it directs distributed creativity towards the same goal, instead of fostering unproductive competition. Decision-makers have too often complacently relied on competition and contradictions among scientists since the unclear recommendations that result from those contradictions make it easy to avoid costly or unpopular actions, even where this is necessary.

Farm redesign is the key to tackling lower productivity without more external input (Bharucha et al., 2020). Various system-related solutions for this are possible. On the one hand, the typical agroecological techniques described above are already doubling yields in subsistence farming. This is because subsistence farmers often neglect simple techniques such as planting annual and perennial legumes, crop rotation, pasture rotation, raising fewer but better fed grazing animals (through improved grassland management), and polyculture. Furthermore, a higher land equivalent ratio (LER) must be attained in as many contexts as possible. Intercropping or polyculture is in any case the future solution. In agroforestry systems, this is mainly a combination of annual crops (cereals, sorghum, many grain legumes, vegetables, flowers, etc.) with fruit trees, wood trees for energy production, cocoa, etc. In scientific literature, polyculture has been reported to give yields 40 to 145 % higher than sole cropping. In this case, the highest increase has been achieved with ginger, maize, and soybean polyculture in Nepal (Chapagain et al., 2018). In temperate climate zones, mixed cultures with only annual plants are more common. Agroforestry systems are still rare as both temperatures and light intensities are too low for two- or three-layer plantings. Popular on organic farms are barley and pea or oats and faba bean. In addition to having a slightly higher LER, they improve the nitrogen supply, soil fertility, and soil physical stability, and they have an excellent weed suppression effect that also reduces the need for mechanical weeding.

Digitalisation is a key technology for enabling highly diversified farms and fields. The digitalisation started with precision farming and was originally implemented in order to use external inputs such as pesticides and fertilisers in a more targeted, economical, and demand-oriented manner. Organic and agroecolocical farmers saw no advantages in precision farming: the former because they generally ban most inputs, while for the latter the technology was expensive and led to dependence on substantial investment. In the meantime, however, this has changed, mainly due to advances in robotics, GPS technology, the tremendous development of remote sensing and hyperspectral image analysis, the speed of wireless data transmission, real-time data processing, and advances in precision of control. Digitalisation increasingly offers opportunities to achieve the goals of agroecological farming systems, representing a turning point in modern agriculture. For the first time, mechanisation is moving away from ever-heavier tractors and back to self-propelled equipment, which is becoming ever smaller and lighter. This is not only good for energy consumption but is even better for physical and biological soil quality. Moreover, the compulsion to simplify landscape structures, grow and level out fields, and remove 'disturbing' habitats is reversed, and the new methods of mechanisation can be adapted to a diverse, small-scale landscape and various local conditions.

Great potential for yield increase also lies in breeding programmes well-adapted to the conditions of low external input cultivation systems and farms. Highly important traits of these are increased resilience or tolerance to plant pests and disease. Equally important is the ability of plants to compensate for growth when the mineralisation of organic fertilisers starts late and take advantage of the microbial activity of the soil. The latter depends, among other things, on root architecture, symbiotic fungi and bacteria in the rhizosphere, and on plant hormones that act as growth and development regulators and activate the induction of disease resistance mechanisms. The fact that plant breeding is important and must adapt to the context of agroecosystems is undisputed. However, there are major differences in the choice of breeding techniques. Organic farmers focus above all on the potential of classical cross-breeding, while others use markers extensively to speed up breeding, and there is now also an intensive discussion about whether targeted mutagenesis with genome editing would be an option, especially for sustainable farming systems where off-farm input is considerably reduced.

## 5 Conclusion

The discussion on agroecology in its current state is pleasantly unagitated and not yet caught up in political quibbles and market interests. This allows a freer and more creative debate. Agroecology is a promising concept of how agricultural practice and research can be geared to the needs of people and the planet. Effects are in the foreground, and synergies are always sought: between nature and technology, productivity and natural resources, scientific knowledge and traditional experience. All actors have a great deal of freedom, provided that the goal is not lost sight of. This orientation towards goals requires a stringent and holistic understanding of sustainability. A productivist farmer optimises yields and efficiency. An organic farmer strives for best compliance with the standards. Future agroecological farmers must strike a more delicate balance. They must mobilise all their skills in order to make responsible use of the freedom offered by a methodology that as yet remains uncodified. They must manage their business in an economically, socially, and ecologically sustainable manner with the help of appropriate evaluation methods. And for now, they experience the same fate of all pioneers: a lack of support from the agricultural research community and established knowledge systems.

### REFERENCES


Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision [online]. Rome: FAO, 153 p, ESA Working paper:12-03. Retrieved from <http://www.fao.org/fileadmin/templates/esa/Global_persepctives/world_ag_2030_50_2012_rev.pdf> [at 18 Sept 2020]

Altieri MA (1995) Agroecology: The science of sustainable agriculture. 2nd Edition. Colorado: Westview Press, 433 p

Armengot L, Barbieri P, Andres C, Milz J, Schneider M (2016) Cacao agroforestry systems have higher return on labor compared to full-sun monocultures. Agron Sustain Dev 36:70, doi:10.1007/s13593-016-0406-6

Bharucha ZP, Mitjans SB, Pretty J (2020) Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. Int J Agr Sustain 18(1):1–20, doi:10.1080/14735903.2019.1694465

Brown T (2009) Change by design: How design thinking transforms organizations and inspires innovation. 1st edition. New York: HarperCollins Publishers, 272 p

Burney JA, Davis SJ, Lobell DB (2010) Greenhouse gas mitigation by agricultural intensification. PNAS USA 107(26):12052–12057, doi:10.1073/pnas.0914216107

Chapagain T, Pudasaini R, Ghimire B, Gurung K, Choi K, Rai L, Magar S, Bishnu BK, Raizada MN (2018) Intercropping of maize, millet, mustard, wheat and ginger increased land productivity and potential economic returns for smallholder terrace farmers in Nepal. Field Crops Res 227: 91–101, doi:10.1016/j.fcr.2018.07.016

De Schutter O (2010) Report submitted by the Special Rapporteur on the right of food, Oliver de Schutter. Human Rights Council, 16th session. Geneva: United Nations, 21 p, A/HRC/16/49. Retrieved from <https://www2.ohchr.org/english/issues/food/docs/a-hrc-16-49.pdf> [at 17 Sept 2020]

EC, European Commission (2013) Regulation (EU) No 1310/2013 of the European Parliament and of the Council of 17 December 2013 [online]. Strasbourg: European Parliament, 19 p. 2013/0117/COD. Retrieved from <http://data.europa.eu/eli/reg/2013/1310/oj> [at 17 Sept 2020]

FAO (2017) The future of food and agriculture – Trends and challenges [online]. Rome: FAO, 180 p. Retrieved from <http://www.fao.org/3/a-i6583e.pdf> [at 17 Sept 2020]

FAO (2018) FAO's work on agroecology: A pathway to achieving the SDG's [online]. Rome: FAO, 28 p. Retrieved from <http://www.fao.org/3/i9021en/I9021EN.pdf> [at 17 Sept 2020]

Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, et al. (2013). Sustainable Intensification in Agriculture: Premises and Politics. Science 341(6141):33–34, doi:10.1126/science.1234485

Gliessman SR (2006) Agroecology: the ecology of sustainable food systems. 3rd edition. London and New York: CRC Press, Taylor & Francis Group, 406 p

Haupt C, Hofer N, Roesch A, Gazzarin C, Nemecek T (2018) Analyse ausgewählter Massnahmen zur Verbesserung der Nachhaltigkeit in der Schweizer Milchproduktion – eine Literaturstudie. Agroscope Science 58:1–75

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]

Jackson T, Victor P (2019) Unraveling the claims for (and against) green growth. Science 366(6468): 950–951, doi:10.1126/science.aay0749

Kumar J, Pradhan M, Singh N (2018) Sustainable organic farming in Sikkim: An inclusive perspective. In: SenGupta S, Zobaa AF, Sherpa KS, Bhoi AK (eds) Advances in smart grid and renewable energy. Singapore: Springer, 367–378, Proceedings of ETAEERE-2016

La Via Campesina (2018) Website. Retrieved from <https://viacampesina.org/en> [at 17 Sept 2020]

Mäder P, Fliessbach A, Dubois D, Gunst L, Fried P, Niggli U (2002) Soil fertility and biodiversity in organic farming. Science 296(5573):1694–1697, doi:10.1126/science.1071148

Müller A, Schader C, Scialabba NEH, Brüggemann J, Isensee A, Erb KH, Smith P, Klocke P, Leiber F, Stolze M, Niggli U (2017) Strategies for feeding the world more sustainably with organic agriculture. Nat Commun 8:1290, doi:10.1038/s41467-017-01410-w

Meek, D., Anderson CR (2020) Scale and the politics of the organic transition in Sikkim, India. Agroecol Sustain Food 44(5):653–672, doi:10.1080/21683565.2019.1701171

Meemken E-M, Qaim M (2018) Organic agriculture, food security, and the environment. Annu Rev Resource Econom 10:39–63, doi:10.1146/annurev-resource-100517-023252

Niggli U (2015) Incorporating agroecology into organic research – An ongoing challenge. Sustain Agric Res 4(3):149–157, doi:10.5539/sar.v4n3p149

Niggli U, Riedel J, Brühl C, Liess M, Schulz R, Altenburger R, Märländer B, Bokelmann W, Heß J, Reineke A, Gerowitt B (2020) Pflanzenschutz und Biodiversität in Agrarökosystemen. Berichte über Landwirtschaft 98(1):1–39, doi:10.12767/buel.v98i1.272

Oel F, Sievering E, Ineichen K, Mäder P, Boller T, Wiemken A (2003) Impact of land use intensity on the species diversity of arbuscular mycorrhzal fungi in agroecosystems of Central Europe. Appl Environ Microbiol 69(5):2816–2824, doi:10.1128/AEM.69.5.2816-2824.2003

Parmentier S (2014) Scaling-up agroecological approaches: what, why and how? [online] Belgium: Oxfam-Solidarity, 93 p. Retrieved from <http://www.fao.org/fileadmin/templates/agphome/scpi/Agroecology/Agroecology_Scaling-up_agroecology_what_why_and_how_-OxfamSol-FINAL.pdf> [at 17 Sept 2020]

Pretty JN (1997) The sustainable intensification of agriculture. Nat Resour Forum 21(4): 247–256, doi:10.1111/j.1477-8947.1997.tb00699.x

Pretty JN, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HCJ, Goulson D, Hartley S, Lampkin N, Morris C, Pierzynski G, et al. (2018) Global assessment of agricultural system redesign for sustainable intensification. Nat Sustain 1(8): 441–446, doi:10.1038/s41893-018-0114-0

Reganold JP, Wachter JM (2016) Organic agriculture in the twenty-first century. Nat Plants 2:15221, doi:10.1038/nplants.2015.221

Rosset PM, Machín Sosa B, Roque Jaime AM, Ávila Lozano DR (2011) The Campesino-to-Campesino agroecology movement of ANAP in Cuba: social process methodology in the construction of sustainable peasant agriculture and food sovereignty. J Peasant Stud 38(1):161–191, doi:10.1080/03066150.2010.538584

Sanders J, Heß J (eds) (2019) Leistungen des ökologischen Landbaus für Umwelt und Gesellschaft. 2nd edition. Braunschweig: Johann Heinrich von Thünen-Institut, 398 p, Thünen Rep 65, doi:10.3220/REP1576488624000

Schader C, Müller A, Scialabba NE, Hecht J, Isensee A, Erb KH, Smith P, Makkar HPS, Klocke P, Leiber F, Schwegler P, et al. (2015) Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. J R Soc Interface 12(113):20150891, doi:10.1098/rsif.2015.0891

Seidl I, Zahrnt A (2019) Erwerbsarbeit, Tätigsein und Postwachstum. In: Zahrnt A (eds) Tätigsein in der Postwachstumsgesellschaft. Marburg: Metropolis-Verlag, 9–24

Seufert V, Ramankutty N (2017) Many shades of gray – The context-dependent performance of organic agriculture. Sci Adv 3(3):e1602638, doi:10.1126/sciadv.1602638

Steffen W, Richardson K, Rockstrom J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA, Folke C, et al. (2015) Planetary boundaries: Guiding human development on a changing planet. Science 347(6223):1259855, doi:10.1126/science.1259855

Tischler W (1965) Agrarökologie. Jena:Gustav Fischer Verlag, 499 p

Tittonell P (2014) Ecological intensification of agriculture – sustainable by nature. Curr Opin Environ Sustain 8: 53–61, doi:10.1016/j.cosust.2014.08.006

TWN and SOCLA (2015) Agroecology: key concepts, principles and practices [online]. Malaysia: Third World Network Penang and Berkeley: Sociedad Científica Latinoamericana de Agroecología. Retrieved from <https://foodfirst.org/agroecology-key-concepts-principles-and-practices/> [at 17 Sept 2020]

Wezel A, Bellon S, Doré T, Francis C, Vallod D, 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

Willer H, Schlatter B, Trávníýek T, Kemper L, Lernoud J (eds) (2020) The world of organic agriculture. Statistics and emerging trends 2020 [online]. Frick: FiBL, Bonn: IFOAM Organics International, 337 p, FIBL-IFOAM Report. Retrieved from <https://www.fibl.org/fileadmin/documents/shop/5011-organic-world-2020.pdf> [at 17 Sept 2020]

POSITION PAPER

# Building alliances between producers and consumers by politicising consumption

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Received: March 19, 2020
Revised: May 27, 2020
Accepted: July 24, 2020

© private

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KEYWORDS **political consumption, up-scaling agroecology, agroecological movements, food sovereignty, political agroecology**

## 1 Description of problem

Over the last decades, agroecology has been inspiring thousands of social innovation initiatives, involving social organisations, researchers, extensionists, cooperation agencies, public managers, and consumers from around the world (Hinrichs, 2014; IPES-Food, 2015; El Bilali, 2019; HLPE, 2019). For the most part, however, these initiatives are local, often segmented, and they account for a very small percentage of food consumption (Gliessman, 2018). These experiences grow quantitatively (scaling out) but, from my point of view, not qualitatively and thus fail to achieve a leap of scale. This fact is not accidental and is due to the 'rejection effect' that the institutional framework subjects them to, leading them to encapsulation, conventionalisation, or simply failure (González de Molina et al., 2020). This rejection is the corporate food regime's defensive response to the threat posed by these experiences. One example is organic food production in Europe: the institutional framework treats it as a distinctive quality label, leading organic production towards 'conventionalisation' through the market. Market imposes comparatively higher costs on organic farming due to the yield gap, the necessary investments in biodiversity, etc. (Darnhofer et al., 2010; Ramos et al., 2018).

To overcome these difficulties, the agroecological movement has proposed scaling-up strategies, for example, the construction of local food systems (Wezel and David, 2012; Fraňková et al., 2017), the redesign of landscapes that makes the closing of biogeochemical cycles possible (Gliessman, 1998; Marull et al., 2019), and a transformation towards a sustainable diet or public policies that favour agroecological transition and change of scale (Ajates Gonzales et al., 2018; Sabourin et al., 2017; Giraldo and McCune, 2019). These strategies so far have had limited results. To implement all these measures in an integrated way and to guarantee a successful outcome, it is necessary to dismantle the existing institutional framework which is based on free-market rules and the hegemony of large food and agricultural input corporations (Heinrich Böll Foundation, 2017). Another way is to create niches that favour social experiments and their leaps of scale. This, however, requires 'social majorities supporting change' to impose the needed institutional change on states' political agendas, which face the lobbying pressures from big corporations and interest groups.

It is not easy to build these majorities of change: the social agents fighting for an alternative food system are still a minority; they are fragmented and mostly local in scope. Furthermore, most of these movements are urban and consumption-focused (SAPEA, 2020), far from the first steps in the food chain. For their part, farmers' movements centre their demands preferentially on fair prices and adequate levels of income. Eu-wide, they have even opposed the banning of certain pesticides in recent months, fearing the possible negative effects that such environmental and consumer protection

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measures could have on their vulnerable economies (van der Ploeg, 2020). In any event, farmers, who represent an ever-smaller share of the electorate, have a limited political influence. In short, the interests present in the food chain are fragmented, and the distance between the interests and expectations in the countryside and the cities is increasing further. This tendency towards fragmentation could be accentuated, in my opinion, by the Ecological Transition and the Green Pact launched by the new European Commission[2] if the "from farm to fork" strategy only supports measures to ban certain chemical plant protection products but not the farmers to make the transition economically viable.

## 2 Possible solution

Obviously, building these majorities of change will only be possible by involving the majority of society in a common political agenda. The task is impossible to accomplish without the required social alliances between producers and consumers. Traditionally, agroecology has exceedingly focused on mobilising the supply side, that is, on working with food producers. At the turn of the century, agroecology left the field of agriculture and demanded a change of orientation towards the food system as a whole, taking all the steps of the chain into account to establish a sustainable food strategy (Francis et al., 2003). But this change of approach has yet to be completed by focusing on mobilising demand or food consumption and assigning healthy food a pivotal role in the demands for practices that are also sustainable throughout the food chain (Schneider and Hoffmann, 2011). A strategy to achieve the change in approach would be to shift the focus currently set on production to eating. Nutrition itself connects multiple dimensions of social relations. Satisfying the endosomatic metabolism of human beings has become increasingly complex: it combines aspects related to physical and mental health, bodily well-being, cultural identity, the preservation of material and intangible heritage, the viability of productive agricultural activities, rural development, the health of agroecosystems, agri-food transformation activities, the sustainability of energy consumption, fair relations between developed and peripheral countries, etc. Food has become an integrating "thematic meeting point" of a range of social, economic, and environmental political spheres, which poses considerable governance challenges that have hitherto been poorly addressed (Renting and Wiskerke, 2010; Petrini et al., 2016).

The Spanish case is an illustration of this complexity. Spanish citizens today follow a diet that has abandoned healthy Mediterranean habits and acquired others that are responsible for over half of the population being obese or overweight (González de Molina et al., 2017). Meat, milk, and other dairy products are the main culprits. Spain is only one example of changes in eating habits worldwide. These changes constitute a major factor of unsustainability, not only with regard to human health but also to the health of agroecosystems (González de Molina et al., 2020). In Spain, all food-related activities as a whole account for 29 % of the primary energy consumed by the nation, including food for export. These eating habits are, in turn, the cause of the massive spillage of polluting substances in the soil, the air, the watercourses, and the food itself (González de Molina et al., 2019). A total of 109 million tons of animal and plant biomass are required by the Spanish to ingest more than 3,400 kcal capita$^{-1}$ day$^{-1}$, that is, 6.65 kg/person/day (Infante-Amate and González de Molina, 2013). The productivity of cropland has significantly multiplied, mainly thanks to the reconversion of irrigated dry land and intensive production under plastic. Meanwhile, a large part of the drylands in the country's interior, is less reactive to external inputs and therefore less productive, and natural pastures are gradually being abandoned (Soto et al., 2016). Paradoxically, vast areas need to be dedicated to grain and fodder production in peripheral countries in order to increase a population of livestock to meet high meat and dairy product demands. Infante-Amate et al. (2018) estimated the amount of 'virtual agricultural land' required by the Spanish diet. The data is overwhelming: Spain exports around 3 million hectares and imports 11 million; the deficit amounts to a total of 8 million hectares.

Consumers' concerns regarding the impacts on the environment and health are growing. Both collective and individual mobilisation around healthy eating is on the rise. But the demands or claims are diverse, fragmented, and even contradictory, and they present an obstacle to the building of a broad social alliance. To achieve such an alliance, it is necessary to reach a totalising political proposal capable of bringing together social groups. This proposal is more likely to arise from the demand side than from the supply side, that is, from the food consumption side. Indeed, the social complexity and the variety of forms of domination existing in post-industrial societies create conditions that favour the emergence of a wide range of conflicts and protests. All these conflicts can be coordinated through general demands or via "empty signifiers", as proposed by Laclau and Mouffe (1985). These empty signifiers or totalising demands must be brought about by the 'politicisation of food consumption', that is, by turning food into a responsible act and therefore a political choice and through questioning the visible deficiencies of the food system, its structural problems, and the search for solutions.

The most obvious path of such politicisation lies in aspects related to human health. Food insecurity has become widespread worldwide under the corporate food regime, associated with cases of undernutrition and overnutrition. Overnutrition is already a common phenomenon in both the North and the South and is linked to increased intake of so-called ultra-processed foods (Monteiro et al., 2013). In high-income countries, poorer people are most affected by overweight and obesity as healthy food is more expensive than food based on processed products rich in sugars, oils, and other fats. The consumption patterns promoted by corporate food regime and publicity (fast food,

[2] European Commission (2020) Financing the green transition: The European Green Deal investment plan and just transition mechanism. Retrieved from <https://ec.europa.eu/commission/presscorner/detail/en/ip_20_17> [at 13 March 2020]

soft drinks, etc.) are "obesogenic" and are not encouraging the adoption of healthy diets (Winson, 2013; Scrinis, 2013; Doytch et al., 2014; CIHEAM/FAO 2015). They present serious operational and governance challenges that are bringing about negative impacts on health with high economic costs (Burlingame and Dernini, 2010; Johnston et al., 2014; Tilman and Clark, 2014). Food is also the cause of the massive spillage of polluting substances in the soil, the air, the watercourses and the food itself (Hallström et al., 2014; Willett et al., 2019).

Another way of politicising consumption is the struggle for recognising the right to food as a human right (Ziegler, 2001). Despite being recognised in some international treaties, including the 'International Covenant on Economic, Social and Cultural Rights'[3], many countries have not yet incorporated it into their legislation. The right to food is not only a matter of access and enjoyment of sufficient amounts of food; it is also a question of nutritional quality and sustainability in the way food safety is produced. The guarantee of this right is, first and foremost, a political issue, one of governance, where the state is fundamentally responsible, but where the participation of society is indispensable. It is essential that public policy is jointly developed by the different actors involved in the food system. This participation can be channelled by creating forums in which to share experiences and generate political proposals appropriate for all citizens. Food Policy Councils (Harper et al., 2009) are a good example of this.

Very interesting discussions on how to feed the cities are currently taking place around the so-called Milan Urban Food Policy Pact (2015). This is a clear example of how food consumption can be politicised[4]. Over 209 cities around the world are taking part, and governance instruments have been created around it. It is the first international protocol at the municipal level, aimed at developing sustainable food systems. It includes a strategic action framework with recommendations to create favourable conditions for effective action, promote sustainable and nutritious diets, ensure social and economic fairness, promote food production, improve supply and distribution, and limit food waste, among other actions. Similarly, but more specifically, agroecological initiatives have sprung up all over the world. Worthy of note in Spain, for example, is the Network of Cities for Agroecology[5], which aims to "create a process of exchange of knowledge, experiences and resources on food policies between Spanish cities that includes local social organisations". Similarly, urban and peri-urban agriculture favours not only the removal of barriers between the countryside and the city but also the politicisation of food consumption in this area.

These and other "generalist" demands for sustainable food also allow the formation of the 'demos' or people who are called upon to exercise food sovereignty (Holt-Giménez and Altieri, 2013). This re-signifies the concept of food sovereignty itself, which can be considered to be more orientated towards access to healthy and sustainable food. It is about overcoming the fragmentation of existing social interests and groups along the food chain by recovering the democratic capacity of citizens to decide (i.e. their sovereignty) what is produced, how it is distributed, and what is eaten. This claim can involve highly diverse social groups, starting with the farmers themselves. The majority of the world population are suffering from the negative impacts of the corporate food regime and are therefore potentially against a regime that is directly responsible for hunger, malnutrition, rural poverty, structural unemployment in agriculture, and significant harm to health and the environment.

## 3 Conclusions

The politicisation of consumption in its various manifestations, in my opinion, seems to be the most effective way of articulating diverse interests towards a unified mobilisation against the corporate food regime. This mobilisation also brings to light the fundamental contradiction between the social majority and a small group of big food corporations. In accordance with Laclau (2005), the role of articulating diverse interests lies precisely in the construction of a global antagonism, capable of creating the agents of social change through mobilisation. The political terrain of health, food democracy or food sovereignty and right to food is where this unifying and emotional discourse on food consumption can most easily thrive, allowing it to generalise protest and challenge the cultural and political hegemony of the corporate food regime.

[3] https://www.ohchr.org/en/professionalinterest/pages/cescr.aspx

[4] https://www.milanurbanfoodpolicypact.org/

[5] https://www.ciudadesagroecologicas.eu/el-proyecto-de-red/

### REFERENCES


Ajates Gonzalez R, Thomas J, Chang M (2018) Translating agroecology into policy: The case of France and the United Kingdom. Sustainability 10(8):2930, doi:10.3390/su10082930

Burlingame B, Dernini S (2010) Sustainable diets and biodiversity. Directions and solutions for policy, research and action. Rome: FAO, 308 p. Retrieved from <http://www.fao.org/3/i3004e/i3004e.pdf> [at 20 Oct 2020]

CIHEAM/FAO (2015) Mediterranean food consumption patterns: diet, environment, society, economy and health [online]. A White Paper Priority 5 of Feeding Knowledge Programme, Expo Milan 2015. Bari/Rome: FAO/CIHEAM, 76 p. Retrieved from <http://www.fao.org/3/a-i4358e.pdf> [at 28 Oct 2020]

Darnhofer I, Lindenthal T, Bartel-Kratochvil R, Zollitsch W (2010) Conventionalisation of organic farming practices: from structural criteria towards an assessment based on organic principles. A review. Agron Sustain Dev 30(1): 67–81, doi:10.1051/agro/2009011

Doytch N, Dave DM, Kelly IR (2014) Global evidence on obesity and related outcomes: An overview of prevalence, trends, and determinants. East Econ J 42(1):7–28, doi:10.1057/eej.2014.37

El Bilali H (2019) Innovation-sustainability nexus in agriculture transition: case of agroecology. Open Agric 4(1)1–16, doi:10.1515/opag-2019-0001

Francis C, Lieblein G, Gliessman S, Breland TA, Creamer N, Harwood T, Salomonsson L, Helenius J, Rickerl D, Salvador R, Wiedenhoeft M et al. (2003) Agroecology: The ecology of food systems. J Sustain Agric 22(3): 99–118, doi.org/10.1300/J064v22n03_10

Fraňková E, Haas W, Singh SJ (eds) (2017) Socio-metabolic perspectives on the sustainability of local food systems. Basel: Springer International, 364 p, doi:10.1007/978-3-319-69236-4

Giraldo OF, McCune N (2019) Can the state take agroecology to scale? Public policy experiences in agroecological territorialization from Latin America. Agroecol Sustain Food 43(7–8):785–809, doi.org/10.1080/21683565.2019.1585402

Gliessman SR (1998) Agroecology: ecological processes in sustainable agriculture. Chelsea, MI: Ann Arbor Press, 357 p
Gliessman S (2018) Scaling-out and scaling-up agroecology. Agroecol Sustain Food 42(8):841–842, doi.org/10.1080/21683565.2018.1481249
González de Molina M, Petersen PF, Garrido Peña F, Caporal FR (2020) Political agroecology. Advancing the transition to sustainable food systems. New York: CRC Press, Taylor & Francis Group, 201 p
González de Molina M, Soto Fernández D, Guzmán Casado G, Infante-Amate J, Aguilera Fernández E, Vila Traver J, García-Ruiz R (2019) The social metabolism of Spanish agriculture, 1900–2008. The mediterranean way towards industrialization. Basel: Springer International, 281 p, doi:10.1007/978-3-030-20900-1
González de Molina M, Soto Fernández D, Infante-Amate J, Aguilera E, Vila Traver J, Guzmán Casado GI (2017) Decoupling food from land: the evolution of Spanish agriculture from 1960 to 2010. Sustainability 9(12):-2348, doi:10.3390/su9122348
Hallström E, Carlsson-Kanyama A, Börjesson P (2014) Environmental impact of dietary change: a systematic review. J Clean Prod 91(March 2015):1–11, doi:10.1016/j.jclepro.2014.12.008
Harper A, Shattuck A, Holt-Giménez E, Alkon A, Lambrick F (2009) Food policy councils: lessons learned. Oakland: Food First, 63 p. Retrieved from <https://foodfirst.org/wp-content/uploads/2014/01/DR21-Food-Policy-Councils-Lessons-Learned-.pdf> [at 20 Oct 2020]
Heinrich Böll Foundation (2017) Agrifood atlas. Facts and figures about the corporations that control what we eat. Berlin/Brussels: Heinrich Böll Foundation, Rosa Luxemburg Foundation, Friends of the Earth Europe, 56 p. Retrieved from <https://eu.boell.org/sites/default/files/agrifood-atlas2017_facts-and-figures-about-the-corporations-that-control-what-we-eat.pdf> [at 20 Oct 2020]
Hinrichs CC (2014) Transitions to sustainability: a change in thinking about food systems change? Agric Human Values 31:143–155, doi:10.1007/s10460-014-9479-5
HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]
Holt-Giménez E, Altieri MA (2013) Agroecology, food sovereignty, and the new green revolution. Agroecol Sustain Food Syst 37(1):90–102, doi:10.1080/10440046.2012.716388
Infante-Amate J, Aguilera E, Palmeri F, Guzmán GI, Soto D, García-Ruiz R, González de Molina M (2018) Land embodied in Spain's biomass trade and consumption (1900–2008): Historical changes, drivers and impacts. Land Use Policy 78: 493–502, doi:10.1016/j.landusepol.2018.07.019
Infante-Amate J, González de Molina M (2013) 'Sustainable de-growth' in agriculture and food: an agro-ecological perspective on Spain's agrifood system (year 2000). J Clean Prod 38: 27–35, doi:10.1016/j.jclepro.2011.03.018
IPES-Food (2015) The new science of sustainable food systems: Overcoming barriers to food systems reform. Brussels: International Panel of Experts on Sustainable Food Systems (IPES-Food), 22 p. Received from<http://www.ipes-food.org/_img/upload/files/NewScienceofSusFood.pdf> [at 24 May 2020]
Johnston JL, Fanzo JC, Cogill B (2014) Understanding sustainable diets: A descriptive analysis of the determinants and processes that influence diets and their impact on health, food security, and environmental sustainability. Adv Nutr 5(4): 418–429, doi:10.3945/an.113.005553
Laclau E (2005) On populist reason. London: Verso, 276 p
Laclau E, Mouffe C (1985) Hegemony and socialist strategy: Towards a radical democratic politics. London: Verso, 240 p
Marull J, Cattaneo C, Gingrich S, González de Molina M, Guzmán GI, Watson A, MacFadyen J, Pons M, Tello E (2019) Comparative energy-landscape integrated analysis (ELIA) of past and present agroecosystems in North America and Europe from the 1830s to the 2010s. Agric Syst 175 (2019) 46–57, doi.org/10.1016/j.agsy.2019.05.011
Monteiro CA, Moubarac JC, Cannon G, Ng SW, Popkin B (2013) Ultra-processed products are becoming dominant in the global food system. Obes Rev 14 (S2): 21–28, doi:10.1111/obr.12107
Petrini C, Bogliotti C, Rava R, Scaffidi C (2016) La centralidad del alimento. Documento congresual 2012–2016. In: El Congreso Mundial de Slow Food, Turin, 27–29 Oct 2012, 25 p. Retrieved from <https://slowfood.com/filemanager/official_docs/SFCONGRESS2012_La_centralidad_del_alimento.pdf> [at 24 May 2020]
Ramos García M, Guzmán GI, González de Molina M (2018) Dynamics of organic agriculture in Andalusia: moving toward conventionalization? Agroecol Sustain Food 42(3):328–359, doi:10.1080/21683565.2017.1394415
Renting H, Wiskerke H (2010) New emerging roles for public institutions and civil society in the promotion of sustainable local agro-food systems. 9th European IFSA Symposium, Vienna (Austria), 4–7 Jul 2010, 11p. Retrieved from <https://edepot.wur.nl/146104> [at 20 Oct 2020]
Sabourin E, Patrouilleau MM, Le Coq J-F, Vázquez L, Niederle PA (eds) (2017) Políticas públicas a favor de la agroecología en América Latina y el Caribe. Porto Alegre, Porto Alegre: Red PP-AL – FAO, 412 p. Retrieved from <http://agritrop.cirad.fr/585670> [at 24 May 2020]
SAPEA (2020) A sustainable food system for the European Union. Berlin: Science Advice for Policy by European Academies (SAPEA), 224 p, Evidence Review Report 7. Retrieved from <https://doi.org/10.26356/sustainablefood> [at 24 May 2020]
Schneider K, Hoffmann I (2011) Nutrition ecology: a concept for systemic nutrition research and integrative problem solving. Ecol Food Nutr 50(1): 1–17, doi:10.1080/03670244.2010.524101
Scrinis G (2013) Nutritionism: The science and politics of dietary advice. New York: Columbia University Press, 368 p
Soto Fernández D, Infante-Amate J, Guzmán GI, Cid A, Aguilera E, García R, González de Molina M (2016) The social metabolism of biomass in Spain, 1900–2008: From food to feed-oriented changes in the agro-ecosystems. Ecol Econ 128:130–138, doi:10.1016/j.ecolecon.2016.04.017
Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515: 518–522, doi:10.1038/nature13959
van der Ploeg JD (2020) Farmers' upheaval, climate crisis and populism. J Peasant Stud 47(3):589–605, doi:10.1080/03066150.2020.1725490
Wezel A, David C (2012) Agroecology and the food system. In: Lichtfouse E (ed) Agroecology and strategies for climate change. Dordrecht: Springer, 17–33, doi:10.1007/978-94-007-1905-7
Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, Jonell M, et al. (2019) Food in the anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet 393(10170):447–492, doi:10.1016/S0140-6736(18)31788-4
Winson A (2013) The industrial diet: The degradation of food and the struggle for healthy eating. Vancouver/Toronto: UBC Press, 352 p
Ziegler J (2001) The right to food. Report by the Special Rapporteur on the right to food, Jean Ziegler. Commission on Human Rights, 57th session. Geneva: United Nations, 32 p, E/CN.4/2001/53. Retrieved from <http://www.righttofood.org/wp-content/uploads/2012/09/ECN.4200153.pdf> [at 20 Oct 2020]

POSITION PAPER

# The agroecology of redesign

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Received: May 8, 2020
Revised: August 18, 2020
Accepted: October 9, 2019

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KEYWORDS **agroecology, redesign, sustainable intensification, innovation platforms**

## 1 Towards sustainability in agroecosystems

The concern for sustainability in agroecosystems centres on the fundamental importance of both agricultural and non-agricultural ecosystems, and their links with farmers and consumers. Agriculture is unique as an economic sector as it directly affects many of the very natural and social assets on which it relies for success (MEA, 2005; FAO, 2011, 2016a; Rockström et al., 2017; Pretty et al., 2018). These influences can be both good and bad. Industrialised and high-input agricultural systems rely for their productivity on simplifying agroecosystems, bringing in external inputs to augment or substitute for natural ecosystem functions, and externalising costs and impacts. Pests tend to be dealt with by the application of synthetic and fossil-fuel derived compounds, wastes flow out of farms into water supplies, and nutrients leach to the soil and groundwater. As a result, there has been widespread and increasing cost to natural ecosystems and human health (Pretty, 2018).

By contrast, sustainable approaches to agriculture seek to use ecosystem services without significantly trading off desired productivity. When successful, the resulting agroecosystems have a positive impact on natural, social and human capital, while unsustainable systems continue to deplete these capital assets. A wide range of different terms for more sustainable agriculture have come into use: for regenerative agriculture, a doubly green revolution, alternative agriculture, an evergreen revolution, agroecological intensification, green food systems, save and grow agriculture, and sustainable intensification (NRC, 2010; Godfray et al., 2010; FAO, 2011, 2016a; Pretty et al., 2018). Many of these draw on earlier traditions and innovations in permaculture, natural farming, the one-straw revolution, and forms of biodynamic and organic agriculture.

All sustainable agricultural systems exhibit a number of common attributes. They aim to:

1. utilise crop varieties and livestock breeds with a high ratio of productivity to make use of externally- and internally-derived inputs;
2. avoid the unnecessary use of external inputs;
3. harness agroecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy, predation and parasitism;
4. minimise or eliminate the use of technologies or practices that have adverse impacts on the environment and human health;
5. make productive use of both human capital in the form of knowledge and capacity to adapt and innovate and of social capital to achieve common landscape-scale change (and thus system-wide improvements to water, pest or soil management);
6. minimise the impacts of systems on externalities such as greenhouse gas emissions, clean water, carbon sequestration, biodiversity, and dispersal of pests, pathogens and weeds.

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## 2 Beyond improved efficiency and substitution to redesign

The concept of sustainability should be open, emphasising values and outcomes rather than means, applying to any size of enterprise, and not predetermining technologies, production type, or particular design components. Central to the concept of all types of sustainable systems is an acceptance that there will be no perfect end point due to the multi-objective nature of sustainability. Thus, no system is expected to succeed forever, with no package of practices fitting the shifting ecological and social dynamics of every location. Hill (1985, 2014) proposed three non-linear stages in these transitions towards sustainability: i) efficiency; ii) substitution; and iii) redesign. While both efficiency and substitution are valuable stages towards system sustainability, they rarely achieve the greatest co-production of both favourable agricultural and environmental outcomes at regional and continental scales (Sandhu et al., 2015).

The first stage: 'Efficiency' focuses on making better use of on-farm and imported resources within existing system configurations. Many agricultural systems are wasteful, permitting natural capital degradation within the farm or the escape of inputs across system boundaries to cause external costs on-farm and beyond. Post-harvest losses reduce food availability: tackling them contributes directly to efficiency gains and amplifies the benefits of yield increases generated by other means. On-farm efficiency gains can arise from targeting and rationalizing inputs of fertiliser, such as through deep-fertiliser placement in Bangladesh used by one million farmers on two million hectares (Mulligan, 2016), and of pesticide and water to reduce use, and cause less damage to natural capital and human health. Such precision farming can incorporate sensors, detailed soil mapping, GPS and drone mapping, scouting for pests, weather and satellite data, information technology, robotics, improved diagnostics and delivery systems to ensure inputs are applied at the rate and time to the right place, and only when needed (Lampkin et al., 2015; Garbach et al., 2017). Automatic control and satellite navigation of agricultural vehicles and machinery can enhance energy efficiency and limit soil compaction.

The second stage: 'Substitution' focuses on the replacement of technologies and practices. The development of new crop varieties and livestock breeds deploys substitution to replace less efficient system components with alternatives, such as plant varieties better at converting nutrients to biomass, tolerating drought and/or increases in salinity, and with resistance to specific pests and diseases. Other forms of Substitution include the release of biological control agents to substitute for inputs; the use of gene silencing pesticides; water-based infrastructure replacing the use of soil in hydroponics; and in no-tillage systems new forms of direct seeding and weed management replacing inversion tillage (Pretty and Bharucha, 2014).

The third stage: 'Redesign' incorporates agroecological processes to achieve impact at scale (both increases in area and numbers of farmers). Redesign centres on the composition and structure of agro-ecosystems to deliver sustainability across all dimensions to facilitate food, fibre and fuel production at increased rates. Redesign harnesses predation, parasitism, allelopathy, herbivory, nitrogen fixation, pollination, trophic dependencies and other agro-ecological processes to develop components that deliver beneficial services for the production of crops and livestock (Gliessman and Rosemeyer, 2009; Gurr et al., 2016). A prime aim is to influence the impacts of agroecosystem management on externalities (negative and positive), such as greenhouse gas emissions, clean water, carbon sequestration, biodiversity, and dispersal of pests, pathogens and weeds. While 'Efficiency' and 'Substitution' tend to be additive and incremental within current production systems, 'Redesign' brings the most transformative changes across systems.

Redesign is, however, a social and institutional as well as an agricultural challenge (Gliessman and Rosemeyer, 2009). Here is a need to create and make productive use of human capital in the form of knowledge and capacity to adapt and innovate, and social capital to promote common landscape-scale change, such as for positive biodiversity, water quantity and quality, pest management, and soil health outcomes (Pretty 2003; FAO, 2019; Pretty et al., 2020).

Redesign is critical as ecological, economic, social and political conditions continue to change across whole landscapes. The changing nature of pest, disease and weed threats illustrates the continuing challenge. New pests and diseases can suddenly emerge in different ways: development of resistance to pesticides; secondary pest outbreaks due to pesticide overuse; climate change facilitating new invasions; and accidental long-distance organism transfer. Recent appearances include wheat blast (*Magnaporthe oryzae*) in Bangladesh (2016), and Fall Army Worm (*Spodoptera frugiperda*) in sub-Saharan Africa (2017) and then in China (2020). The papaya mealybug (*Paracoccus marginatus*) is native to Mexico, but spread to the Caribbean in 1994 and then to the Pacific islands by 2002. It was reported in Indonesia, India and Sri Lanka by 2008, then appeared in West Africa; the preferred host is papaya, but it has now colonised mulberry, cassava, tomato and eggplant. Each geographic spread, each shift of host, requires redesigns of local agricultural systems, and rapid responses from research and extension. Such new pests and diseases may also impact crop pollinators, as illustrated by host shifts and the accidental anthropogenic spread of bee parasites (e.g. *Varroa* mites) and pathogens (e.g. *Nosema ceranae*) (Goulson et al., 2015).

## 3 Social capital for redesign

For redesigned agricultural and landscape systems to have a transformative impact on whole landscapes then cooperation is required, or at least individual actions that collectively result in additive or synergistic benefits. For farmers to be able to adapt their agroecosystems in the face of stresses, they will need to have the confidence to innovate. As ecological, climatic, and economic conditions change, and as knowledge evolves, so must the capacity of farmers and communities also evolve to allow them to drive transitions through processes of collective social learning. This suggests redesigned systems have the valued property of intrinsic adaptability, whereby interventions that can be adapted by users to evolve with changing environmental, economic and social conditions are likely to be more sustainable than those requiring a rigid set of conditions to function. Every example of successful redesign at scale has involved the prior building of social capital (Ostrom, 1990; Pretty et al., 2020), in which emphasis is paid to: i) relations of trust, ii) reciprocity and exchange, iii) common rules, norms and sanctions, and iv) connectedness in groups. As social capital lowers the costs of working together, it facilitates co-operation, and people have the confidence to invest in collective activities, knowing that others will do so too. They are also less likely to engage in free-rider actions that result in resource degradation.

Many forms of social capital have emerged in support of transitions towards greater sustainability and equity. These include transnational farmer movements, such as La Vía Campesina with 200 million families represented worldwide (Martínez-Torres and Rosset, 2014), national land rights and anti-land grab movements, such as MST (Movimento dos Trabalhadores Rurais Sen Terra: Veltmeyer, 2019), national rural unions (Welch and Sauer, 2015) and agroecology and social movements (Veltmeyer, 2019). At the same time, organisation around food has advanced in the form of food sovereignty and justice movements (McMichael, 2013) and alternative food networks (AFNs) and alternative food movements (AFMs), particularly from urban food production landscapes and many involving consumers as well as growers/farmers (Desmarais and Wittman, 2014; Saulters et al., 2018).

The concept of system redesign implies the establishment of new knowledge economies for agriculture and land (MacMillan and Benton, 2014). It is clear that the technologies and practices increasingly exist to provide both positive food and ecosystem outcomes: new knowledge needs to be co-created and deployed in an interconnected fashion, with an emphasis on ecological and technological innovation (Willyard et al., 2018). There have been many adaptations in terminology for these systems of co-learning: farmer field school, learning lab, science and technology backyard platform, science field shops, junior life schools, innovation platform, farmer-led council, agro-ecosystem network, farmer cluster network, joint liability group, land care group and epistemic community. What is common to these social innovations has been an understanding that individual farmers, scientists, advisors and extensionists also undertake a transformative journey. Their worldviews are challenged and change, resulting in the formation of broader epistemic communities of common interest (Norgaard, 2004), that utilise, synthesise and apply knowledge and skills from many sources. For sustainable outcomes, cognitive social capital in the form of beliefs and worldviews also changes.

A recent study assessed the formation of social groups within specific geographical territories in eight categories of agricultural and land management intervention (*Figure 1*; Pretty et al., 2020). Across the eight categories and 122 distinct initiatives, it was shown that 8.54 million intentionally-formed social groups had been formed worldwide (Pretty et al., 2020). These comprised groups collectively managing 300 million hectar of agricultural and non-agricultural land. This represents a growth in these types of groups from 0.005 million at the end of the 1980s (primarily in participatory irrigation management) to 0.48 million in 2001 (Pretty and Ward, 2001), and now to 8.54 million by 2020 (exponential fit: R=0.982). *Figure 1* shows the marginal increase between 2000 to 2020 in groups in each of the eight categories.

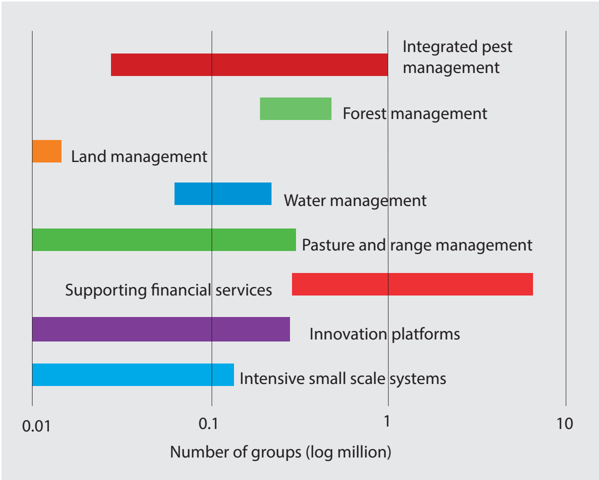


FIGURE 1
Increase in numbers of groups in eight categories of sustainable agriculture and land management (2000–2020) (Source: Pretty et al., 2020).

## 4 Impacts of redesign

It has become clear that social capital established in the form of groups can lead to optimal outcomes for members of these groups. But by definition, those people outside may be excluded from the benefits of membership. This phenomenon of "the dark-side of social capital" (Coleman, 1990) has seen both elite capture (the already wealthy or more powerful individuals using groups to strengthen personal benefit at the expense of others), exclusion (group membership restricted to only some members of a population or location), and negative selection (where individuals are actively excluded). Nonetheless, the majority of the literature points to the benefits of social capital to i) individuals, groups/communities, ii) agricultural systems, and iii) wider landscapes and ecosystem services.

For individuals, groups/communities, there is evidence of changes to personal capabilities and growth, to worldviews, and locally-generated resource availability, through emergence of new leaders of groups, especially by women (Agarwal, 2018), and changes in the relationships between women and men (Westerman et al., 2005); the positive role of women leaders is seen in group effectiveness and conflict resolution over common resources (Coleman and Mwangi, 2013); and changes in the worldviews of farmers (Campbell et al., 2017; van den Berg et al., 2020), as well as of scientists and extensionists working with farmers in novel innovation platforms (Zhang et al., 2016).

For agricultural systems, there is evidence of increased system outputs and reduced input needs, through increases in crop productivity, such as by farmer field schools on all crops (FAO, 2019), and in grazing and pasture productivity (NRC, 2010); increases in tree and agroforestry cover on farms (Garrity et al., 2010; Bunch, 2018); reductions in the use of pesticides in integrated pest management (Yang et al., 2014); and adoption of organic and zero-budget systems (Reganold and Wachter, 2016; Bharucha et al., 2020).

To natural capital and key ecosystem services, there is evidence of increased productivity and reductions in use of harmful or potentially-harmful compounds and releases through increases in irrigation water availability and efficiency of use (Zhou et al., 2017); improvements in forest productivity of wood, forage and secondary products (FAO, 2016b); increases in carbon sequestration in soils by conservation agriculture (Lal, 2014); and reductions in surface water flows and soil erosion (Reij and Smaling, 2008).

## 5 Policy challenges for sustainability transitions

Despite this progress on the ground towards sustainable systems relying on agroecological principles and building both natural and social capital, state policies for transitions toward sustainability remain poorly developed or counter-productive. In the EU, farm subsidies have increasingly been shifting towards targeted environmental outcomes rather than payments for production, but this has not as yet guaranteed synergistic benefits across whole landscapes (Maréchal et al., 2018). Several countries have offered explicit public policy support to social group formation, such as for Landcare (Australia), watershed management (India), joint forest management (India, Nepal, DR Congo), irrigation user groups (Mexico) and farmer field schools (Indonesia, Burkina Faso).

In India's state of Andhra Pradesh, the state government has made explicit its support to community-based natural farming (formerly zero-budget natural farming: ZBNF), aiming to reach six million farmers by 2027 (Bharucha et al., 2020; Smith et al., 2020). In Bhutan and the Indian states of Kerala and Sikkim, policy commitments have been made to convert all land to organic agriculture (Meek and Anderson, 2020); the greening of the Sahel through agroforestry began when national tree ownership regulations were changed to favour local people (Waldron et al., 2017). In China, new national policy frameworks emphasise innovation, coordination, greening and sharing as key parts of a new strategy for the greening of agricultural systems (Xinhua, 2016). And across the world, consumers are increasingly playing a role in connecting directly with farmers, such as through group purchasing schemes, farmers' markets and certification schemes, which may in turn change consumption choices (Allen et al., 2017).

The key question thus centres on what could happen next. Sustainable agriculture approaches have been shown to increase productivity, raise system diversity, reduce farmer costs, reduce negative externalities, and improve ecosystem services. There is thus a range of potential motivations for farmers to adopt agroecological approaches on farm, and for policy support to be provided by national government, third sector and international organisations. But sustainable transitions still require investments to build natural, social and human capital: redesign is not costless. A recent global assessment of sustainable intensification (SI) showed that projects-initiatives in some 100 countries containing 163 million farms have crossed an important substitution-redesign threshold, and are using SI methods, on an area approaching 453 million hectar of agricultural land (Pretty et al., 2018). This comprises 29 % of all farms worldwide; and 9 % of agricultural land (total worldwide crop and pasture land is $4.9 \times 10^9$ hectares). In every case, social capital formation leading to knowledge co-creation has been a critical pre-requisite. In every case, too, farmer benefit (e.g. food output, income, health) was demonstrated and understood.

There are important arguments that suggest the world would not need to increase agricultural production if less food were wasted, and less energetically-inefficient meat was consumed by the affluent. These changes would help, but there is no magic wand of redistribution. Most, if not all, farmers need to raise yields while improving environmental services. The evidence shows that redesign of agro-ecosystems around agroecological approaches to sustainability can achieve yield increases. The evidence from farms of redesign and transformations offers scope for optimism. The concept and practice embodied in the application of agroecology will be a process of adaptation and redesign, driven by a wide range of actors cooperating in new agricultural knowledge economies.

REFERENCES

Agarwal B (2018) Can group farms outperform individual family farms? Empirical insights from India. World Development 108:57–73, doi:10.1016/j.worlddev.2018.03.010

Allen IV JE, Rossi J, Woods TA, Davis AF (2017) Do community supported agriculture programmes encourage change to food lifestyle behaviours and health outcomes? New evidence from shareholders. Int J Agric Sustain 15(1):70–82, doi:10.1080/14735903.2016.1177866

Bharucha ZP, Mitjans SB, Pretty J (2020) Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. Int J Agr Sustain 18(1):1–20, doi:10.1080/14735903.2019.1694465

Bunch R (2018) Restoring the soil: a guide for using green manure/cover crops to improve the food security for smallholder farmers. 2nd edition. Winnipeg: Canadian Foodgrains Bank, 96 p

Campbell A, Alexandra J, Curtis D (2017) Reflections on four decades of land restoration in Australia. Rangeland J 39(5), 405–416, doi:10.1071/RJ17056

Coleman EA, Mwangi E (2013) Women's participation in forest management: A cross-country analysis. Glob Environ Change 23(1):193–205, doi:10.-1016/j.gloenvcha.2012.10.005

Coleman J (1990) Foundations of social theory. Cambridge, MA: Harvard University Press, 1014 p

Desmarais AA, Wittman H (2014) Farmers, foodies and First Nations: getting to food sovereignty in Canada. J Peasant Stud 41(6): 1153–1173, doi:10.1080/03066150.2013.876623

FAO (2011) Save and grow: A policymaker's guide to the sustainable intensification of smallholder crop production. Rome: FAO, 104 p. Retrieved from <http://www.fao.org/3/a-i2215e.pdf> [at 20 Oct 2020]

FAO (2016a) Save and grow in practice: maize, rice and wheat. A guide to sustainable cereal production. Rome: FAO, 124 p. Retrieved from <http://www.fao.org/3/a-i4009e.pdf> [at 20 Oct 2020]

FAO (2016b) Forty years of community-based forestry. Rome: FAO, 168 p. Retrieved from <http://www.fao.org/3/a-i5415e.pdf> [at 20 Oct 2020]

FAO (2019) Farmers taking the lead. Thirty years of famer field schools. Rome: FAO, 72 p. Retrieved from <http://www.fao.org/3/ca5131en/ca5131en.pdf> [at 20 Oct 2020]

Garbach K, Milder JC, DeClerck FA, Montenegro de Wit M, Driscoll L, Gemmill-Herren B (2017) Examining multi-functionality for crop yield and ecosystem services in five systems of agroecological intensification. Int J Agric Sustain 15(1):11–28, doi:10.1080/14735903.2016.1174810

Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, Mowo JG, Kalinganire A, Larwanou M, Bayala J (2010) Evergreen agriculture: a robust approach to sustainable food security in Africa. Food Secur 2:197–214, doi:10.1007/s12571-010-0070-7

Gliessman SR, Rosemeyer M (eds) (2009) The conversion to sustainable agriculture: principles, processes, and practices. Boca Raton: Taylor and Francis Group, CRC Press, 352 p

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327(5967): 812–818, doi:10.1126/science.1185383

Goulson D, Nicholls E, Botías C, Rotheray EL (2015) Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science 347(6229):1255957, doi:10.1126/science.1255957

Gurr GM, Lu Z, Zheng X, Xu H, Zhu P, Chen G, Yao X, Cheng J, Zhu Z, Catindig JL, Villareal S, et al. (2016) Multi-country evidence that crop diversification promotes ecological intensification of agriculture. Nat Plants 2(3):1–4, doi:10.1038/nplants.2016.14

Hill S (1985) Redesigning the food system for sustainability. Alternatives 12(3):32–36

Hill S (2014) Considerations for enabling the ecological redesign of organic and conventional agriculture: a social ecology and psychological perspective. In: Bellon S, Penvern S (eds) Organic farming, prototype for sustainable agriculture. Dordrecht: Springer, 401–422, doi:10.1007/978-94-007-7927-3_22

Lal R (2014) Abating climate change and feeding the world through soil carbon sequestration. In: Dent D (ed) Soil as world heritage. Dordrecht: Springer, 443–457, doi:10.1007/978-94-007-6187-2_47

Lampkin NH, Pearce BD, Leake AR, Creissen H, Gerrard CL, Girling R, Lloyd S, Padel S, Smith J, Smith LG, Vieweger A, Wolfe MS (2015) The role of agroecology in sustainable intensification. Report for the Land Use Policy Group. Newbury/Fordingbridge: Organic Research Centre, Elm Farm and Game & Wildlife Conservation Trust, 163 p. Retrieved from <https://www.nature.scot/role-agroecology-sustainable-intensification-lupg-report> [at 20 Oct 2020]

MacMillan T, Benton T (2014) Engage farmers in research. Nature 509(7498):-25–27, doi:10.1038/509025a

Maréchal A, Baldock D, Hart K, Erjavec E, Rac I, Vanni F, Mantino F (2018) Policy lessons and recommendations from the PEGASUS project. London: Institut for European Environmental Policy (IEEP), 37 p, Deliverable 5.4, PEGASUS project

Martínez-Torres ME, Rosset PM (2014) Diálogo de saberes in La Vía Campesina: food sovereignty and agroecology. J Peasant Stud 41(6):979–997, doi:-10.1080/03066150.2013.872632

McMichael P (2013) Food regimes and agrarian questions. Halifax: Fernwood Publishing, 196 p

MEA, Millennium Ecosystem Assessment (2005) Ecosystems and well-being: synthesis. Washington DC: Island Press, 138 p. Retrieved from <https://www.millenniumassessment.org/documents/document.356.aspx.pdf> [at 20 Oct 2020]

Meek D, Anderson CR (2020) Scale and the politics of the organic transition in Sikkim, India. Agroecol Sustain Food 44(5):653–672, doi:10.1080/21683565.2019.1701171

Mulligan K (2016) Fertilizer deep placement. Washington DC: USAID, Feed the Future, 6 p. Retrieved from <https://www.agrilinks.org/sites/default/files/resource/files/ING%20Tech%20Profile%20(2016_07)%20Fertilizer%20Deep%20Placement%20(Bangladesh).pdf> [at 20 Oct 2020]

Norgaard RB (2004) Learning and knowing collectively. Ecol Econ 49(2):231–241, doi:10.1016/j.ecolecon.2004.03.021

NRC, National Research Council (2010) Towards sustainable agricultural systems in the 21st century. Washington, DC: National Academies Press, 598 p

Ostrom E (1990) Governing the commons: The evolution of institutions for collective action. Cambridge: Cambridge University Press, 280 p. Retrieved from <https://wtf.tw/ref/ostrom_1990.pdf> [at 20 Oct 2020]

Pretty J (2003) Social capital and the collective management of resources. Science 302(5652):1912–1914, doi:10.1126/science.1090847

Pretty J (2018) Intensification for redesigned and sustainable agricultural systems. Science 362(6417):eaav0294, doi:10.1126/science.aav0294

Pretty J, Attwood S, Bawden R, van den Berg H, Bharucha ZP, Dixon J, Butler Flora C, Gallagher K, Genskow K, Hartley SE, Ketelaar JW, et al. (2020) Assessment of the growth in social groups for sustainable agriculture and land management. Glob Sustainability 3(e23):1–16, doi:10.1017/sus.2020.19

Pretty J, Benton TG, Bharucha ZP, Dicks LV, Butler Flora C, Godfray HCJ, Goulson D, Hartley S, Lampkin N, Morris C, Pierzynski G, et al. (2018) Global assessment of agricultural system redesign for sustainable intensification. Nat Sustain 1:441–446, doi:10.1038/s41893-018-0114-0

Pretty J, Bharucha ZP (2014) Sustainable intensification in agricultural systems. Ann Bot 114(8):1571–1596, doi:10.1093/aob/mcu205

Pretty J, Ward H (2001) Social capital and the environment. World Development 29(2):209–227, doi:10.1016/S0305-750X(00)00098-X

Reganold JP, Wachter JM (2016) Organic agriculture in the twenty-first century. Nat Plants 2(2):15221, doi:10.1038/nplants.2015.221

Reij CP, Smaling EMA (2008) Analyzing successes in agriculture and land management in Sub-Saharan Africa: Is macro-level gloom obscuring positive micro-level change? Land Use Policy 25(3):410–420, doi:10.-1016/j.landusepol.2007.10.001

Rockström J, Williams J, Daily G, Noble A, Matthews N, Gordon L, Wetterstrand H, DeClerck F, Shah M, Steduto P, Fraiture C, et al. (2017) Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio 46:4–17, doi:10.1007/s13280-016-0793-6

Sandhu H, Wratten S, Costanza R, Pretty J, Porter JR, Reganold J (2015) Significance and value of non-traded ecosystem services on farmland. PeerJ 3:e762, doi:10.7717/peerj.762

Saulters MM, Hendrickson MK, Chaddad F (2018) Fairness in alternative food networks: an exploration with midwestern social entrepreneurs. Agric Hum Val 35(3):611–621, doi:10.1007/s10460-018-9852-x

Smith J, Yeluripati J, Smith P, Nayak DR (2020) Potential yield challenges to scale-up of zero budget natural farming. Nat Sustain 3(3):247–252, doi:10.1038/s41893-019-0469-x

van den Berg H, Ketelaar JW, Dicke M, Fredrix M (2020) Is the farmer field school still relevant? Case studies from Malawi and Indonesia. NJAS–Wageningen Journal of Life Sciences 92:100329, doi:10.1016/j.njas.2020.100329

Veltmeyer H (2019) Resistance, class struggle and social movements in Latin America: contemporary dynamics. J Peasant Stud 46(6):1264–1285, doi:10.1080/03066150.2018.1493458

Waldron A, Garrity D, Malhi Y, Girardin C, Miller DC , Seddon N (2017) Agroforestry can enhance food security while meeting other sustainable development goals. Trop Conserv Sci 10:1–6, doi:10.1177/1940082917-720667

Welch CA, Sauer S (2015) Rural unions and the struggle for land in Brazil. J Peasant Stud 42(6):1109–1135, doi:10.1080/03066150.2014.994511

Westerman O, Ashby J, Pretty J (2005) Gender and social capital: the importance of gender differences for the maturity and effectiveness of natural resource management groups. World Dev 33(11):1783–1799, doi:10.1016/j.worlddev.2005.04.018

Willyard C, Scudellari M, Nordling L (2018) How three research groups are tearing down the ivory tower. Nature 562(7725):24–28, doi:10.1038/d41586-018-06858-4

Xinhua (2016) CPC and state council guide opinion on using new development concepts to accelerate agricultural modernisation and realise moderate prosperity society. Retrieved from <http://www.xinhuanet.com//fortune/2016-01/27/c_1117916568.htm> [at 24 May 2020]

Yang PY, Zhao ZH, Shen ZR (2014) Experiences with implementation and adoption of integrated pest management in China. In: Peshin R, Pimentel D (eds) Integrated pest management. Chapter 12. Dordrecht: Springer Netherlands, 307–330, doi:10.1007/978-94-007-7802-3

Zhang W, Cao G, Li X, Zhang H, Wang C, Liu Q, Chen X, Cui Z, Shen J, Jiang R, Mi G , et al. (2016) Closing yield gaps in China by empowering smallholder farmers. Nature 537: 671–674, doi:10.1038/nature19368

Zhou Q, Deng X, Wu F, Li Z, Song W (2017) Participatory irrigation management and irrigation water use efficiency in maize production: evidence from Zhangye City, Northwestern China. Water 9(11):822, doi:10.3390/w9110822

POSITION PAPER

# Soil organic carbon certificates – potential and limitations for private and public climate action

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Received: April 4, 2020
Revised: July 7, 2020
Accepted: September 10, 2020


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KEYWORDS **soil organic matter, carbon footprint, carbon farming, carbon neutral crop production, climate change mitigation, sustainable soil management**

## 1 Description of problem

Climate-smart use of soils for arable crop production encompasses all efforts leading to adaptation to climate change and to mitigation of greenhouse gas (GHG) emissions from soils and land use. Increasing soil organic carbon (SOC) using agricultural measures, as reviewed by Merante et al. (2017) and Wiesmeier et al. (2020), is regarded as a negative emission technology (Lal, 2019; Smith, 2016; 4 per Mille, 2020). It is also relevant for ensuring sustainable soil fertility and for saving mineral N-fertilisers and related emissions. Thus, upcoming benchmarking systems, such as 'C-footprint' and 'C-neutral production', of arable products (Stoessel et al., 2012), for farms and businesses are gaining interest as part of agro-ecological concepts (Saj and Torquebiau, 2018). A number of initiatives were developed world-wide in recent years (CarboCert, 2020; Carbon Farmers of Australia, 2020; ÖkoregionKaindorf, 2020; Zero Foodprint, 2020; Wesseler, 2020) acting as agencies for private and, so far, regional trade in SOC-certificates sold on the private market for offsetting individual or business GHG-emissions. However, questions remain about their consideration in country-level GHG-accounting in relation to mitigation targets. Governments are obliged to report SOC-changes within the sector 'Land Use and Land Use Change' (LULUCF) under the United Nations Framework Convention on Climate Change (UNFCCC) and the European Union (EU) climate change mitigation policy (European Parliament and the Council of the European Union, 2018[5]). Moreover, all emissions ($CO_2$-C losses from C-sinks) and removals (increases in C-sinks) in arable land, grassland and forestry count towards the 'no-debit' target of the LULUCF-Regulation from 2021 onwards (i.e. no increase in GHG-net-emissions, including C-removals in the LULUCF sector). In their national reporting duties, many countries claim that the SOC-stock in arable soils is stable. National soil monitoring programmes, e.g. 'National Soil Inventory' (Thünen Institute 2020a, 2020b) in Germany, are improving current methodologies by replacing stable SOC-stocks assumptions with values measured at regular intervals and/or estimated by dynamic modelling.

Farmers play an important part in reducing GHG-emissions from the agriculture and LULUCF sectors.

Recently, in a German publication, Wiesmeier et al. (2020) proposed minimum sampling schemes and analytical standards to evaluate long term SOC changes and discussed opportunities and challenges arising from possible measures to increase SOC. Further, the authors elaborated

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on general limits of SOC-related $CO_2$-certificates for climate protection (e.g. leakage effects, spill-over effects, reversibility, and translocation). However, they also commented on the positive role of $CO_2$-initiatives and of payments to support farmers' initial activities. Thamo and Pannell (2016) also assessed permanence, additionality and leakage as crucial areas of uncertainty and were sceptical about the success of long-lasting policy design to promote SOC-sequestration.

With this paper we pursue this discussion by further evaluation of practical limits for proper SOC-reporting and accounting. We examine the potential for sensible positioning of SOC-initiatives in national GHG-accounting.

## 2 General challenges with soil organic carbon certificates

Key challenges with a trade in SOC-based private certificates arise from the natural realities of SOC-storage and its detectability, leakage effects and other limitations.

One important challenge is the 'reversibility' of SOC-storage. The dynamics of SOC-sequestration are well understood (see e.g. Minasny et al., 2017; Smith, 2004). The sequestration of SOC follows a simplified 'slow in–fast out' pattern (e.g. Poeplau et al., 2011), meaning that SOC-increase takes time and that measures need to be applied continuously. Otherwise, the C accumulated will be lost and emitted as $CO_2$ and the long-term net GHG-mitigation effect will be zero. Moreover, the quality of SOC is important, since SOC-compounds that are labile to microbial mineralization are more prone to loss than stabile SOC-compounds (von Lützow et al., 2006). Certification schemes thus need to establish a soil management system for reaching and maintaining a new SOC-equilibrium, i.e. new steady state of C-input and $CO_2$-C loss (e.g. Kell, 2012) over a long time through continued improved soil management, including the period after increase when no new certificate (no further SOC-increase) is generated. On a field scale, this requires measures that can be monitored over time. Promising measures, such as long-lasting changes in crop rotations (e.g. integration of multiannual green-forage crops, cover crops, deep-rooting crops), require know-how transfer, social support (Demenois et al., 2020) and moderate monetary investments depending on regional circumstances (e.g. Pellerin et al. (2017) reported a mean cost of 38 Euro $ha^{-1}$ $yr^{-1}$ for cover crop cultivation in France). Measures on landscape scale which establish permanent and protected ecosystems (hedgerows, grassland) or permanent land-use types (e.g. fibre-woods, berries, nuts, paludiculture) are still reversible but not as easily as agronomic measures. Thus, such landscape measures are more reliable for long-term 'C-sequestration' (not restricted on SOC). In the 'Carbon Farmers of Australia' (2020) SOC-scheme, these landscape measures are listed as further options for C-certificates. Hedgerows and permanent grassland have positive effects for the entire ecosystem (protection against erosion, increased biodiversity, varied landscape), but may compete with crops for water and nutrients (Sudmeyer et al., 2012) or cause leakage effects (see below) which need to be considered. However, in contrast to field-scale measures, landscape-scale measures can be better monitored and controlled to ensure a long-term implementation. However, such fundamental changes in land-use bring a change in products harvested and would need large financial incentives, at least initially.

A problematic issue for proper and justifiable certification of SOC-stock changes is the 'difficulty in detectability': A change in SOC needs time to reach a level that can be detected by current soil sampling and laboratory protocols. There are high expectations for new sensor-based technologies, including small-scale sensors and remote sensing. So far, these provide higher resolution, but are not sensitive enough to detect changes in SOC-stocks (Stevens and van Wesemael, 2008; Stevens et al., 2008). Moreover, these methods have higher uncertainties, which can prolong the period until significant SOC-stock changes can be detected. Soil sampling and analysis should be conducted by well-trained personnel and using standardised protocols concerning replicates per field, depth and time of sampling. These requirements all add to high costs. To protect farmers from the case that SOC-increases are not detected and, thus, 'SOC-duties' arise, contracts between farmers and providers of SOC-certificates should extend over long time-scales, e.g. 20 years. This would also increase the duration of measures, which is needed to ensure SOC-increase and GHG-mitigation effects. Since the effect of a measure on SOC is neither guaranteed nor verifiable in advance, we question the fairness of the current practice of issuing SOC-certificates in advance of real and detectable effects.

A SOC-change detectable within five years, a period often used in current SOC-certification schemes, can only be achieved by extremely high C-inputs from external sources (Blanco-Canqui and Lal, 2007; Maillard and Angers, 2014). German croplands have an average SOC-stock of 60 Mg $ha^{-1}$ in the top 30 cm and an average SOC-content of 1.5 % (Jacobs et al., 2018). As a theoretical example, this means that an increase of 0.1 % SOC, which is the minimum needed to detect any changes on accounting for small-scale variability and uncertainty of analysis, needs raising the SOC-stock by 4 Mg $ha^{-1}$. Retention coefficient (proportion of added C retained as SOC in Mg $Mg^{-1}$) for straw and farmyard manure is usually found to reach a maximum of 0.15 and 0.3, respectively (e.g. Kätterer et al., 2011). Thus, the SOC-increase of 0.1 percentage points requires an average per-hectare addition of 27 Mg straw-C (60 Mg straw dry mass) or 12 Mg farmyard manure-C (133 Mg fresh farmyard manure). The SOC-certification scheme of ÖkoregionKaindorf (2020) defines 'success' as an increase of the SOC-content by 0.3 percentage points within five years. This can certainly be reached only by extremely high amounts of C-input concentrated on a small area.

The above is one example of the 'dilemma of translocation and dilemma of leakage'. If the application of transportable SOC-sources, e.g. farmyard manure or compost, is concentrated on selected fields, a net GHG-mitigation effect will not be achieved, since SOC-inputs will be suspended in other fields because the overall amount of organic fertilisers available will not increase. Using internal, farm-own, organic fertilisers to stabilise SOC is obviously appropriate and part of good agricultural practice. However, over-application using translocated external sources to reach certification goals is inappropriate and needs to be excluded from SOC-certification schemes. Moreover, measures to increase SOC may have negative side-effects, e.g. nitrogen leaching, increased nitrous oxide emissions, or a shift of GHG-emissions to other sources (e.g. when expansion of grassland is followed by an increase in number of ruminants and related emissions). Such side-effects should be prevented by stringent planning and documentation of measures to increase SOC through ex-ante impact assessments. They should at least be taken into account in quantification of GHG-mitigation (e.g. MoorFutures, 2020).

## 3 Soil organic carbon certificates and national greenhouse gas accounting

Private SOC-initiatives seek to generate market revenues by selling SOC-certificates as $CO_2$-certificates on the voluntary C-market, serving businesses and individuals in offsetting GHG-emissions. Voluntary C-certificates are not valid as offsets within the EU Emissions Trading System. Under most voluntary C-market standards (e.g. Gold Standard, 2020), SOC-certificates must comply with the quality requirement for 'environmental integrity'. This means that offsets have to be real, not double-counted, and must be additional compared with a projection without the offsetting activity (Gold Standard, 2020; Kollmuss et al., 2008; Ministère de la Transition Écologique et Solidaire, 2020). In particular, voluntary C-certificates must be additional to GHG-mitigation activities and targets set by government (Valatin, 2012). Under the Paris Agreement, the aspect of 'additionality' is more challenging than under the Kyoto protocol, as the Paris Agreement has global coverage and its ambition is to introduce global net-zero targets (United Nations 1998, 2015). Thus, the interrelations between private SOC-certificates, state policies and national GHG-mitigation targets need clarification, especially concerning the following four major dilemmas.

The 'dilemma of additionality' can be split into two aspects:

(a) 'Double-claiming of GHG-mitigation effects': The LULUCF-regulation requires member states to improve their GHG-emissions reporting, e.g. by measuring SOC-stocks regularly. Thus, relevant SOC-increases and losses, including those on fields under a private SOC-certification scheme, are reported in national GHG-inventories. As long as there is no mechanism for distinguishing between the effects of private and policy-induced activities, the national government will claim the GHG-mitigation as a contribution to national targets and private SOC-certificates will not make any additional contribution.

(b) 'Double-regulating and double-funding': Activities already included in good agricultural practice or supported by the EU's Common Agricultural Policy (CAP), e.g. catch crop cultivation, are not additional. Thus, the additional benefit of GHG-mitigation needs to be discussed thoroughly and stated in SOC-certification schemes (e.g. special cover crops not funded under the CAP).

The 'dilemma of lacking net GHG-mitigation effects': Assuming that the amount of organic fertilisers available today, e.g. compost from biowaste, does not increase and is used according to 'good agricultural practice', only organic fertilisers produced from additional biomass would provide additional GHG-mitigation. Otherwise, the overall amount of organic fertilisers will not increase but will simply be translocated. To cope with this dilemma, SOC-certification schemes need to achieve net-effects by excluding 'translocation and leakage' effects (see above).

The 'dilemma of reporting': Fields or areas participating in a SOC-certification scheme need to be integrated into existing harmonised, intensive and reliable national soil monitoring to cope with the 'difficulty in detectability'. Alternative methods for soil monitoring and GHG-reporting need to cover many details (e.g. management data for each field and information on the kind of certification scheme), resulting in high costs (e.g. setting-up the database for the SOC-scheme ÖkoregionKaindorf needed about 300,000 Euro (Forstner, 2019); see also above).

The 'dilemma of non-permanence and reversibility': When a soil or field is under a SOC-certification contract and SOC is lost some years later for some reason, the contract needs to stipulate beforehand which party will be accountable and bear the loss of investment costs. This makes SOC-certificates less reliable in the long-run than certificates based on yearly emission reductions (e.g. elevated groundwater level in organic soils).

## 4 Conclusions

All activities resulting in increases in SOC in agricultural soils must be encouraged, as there is global potential for additional $CO_2$-C-sequestration in soils. Moreover, maintenance of SOC has positive effects on soil fertility, as it improves biodiversity, water-holding capacity, plant nutrition, erosion control, soil structure stability, and yield stability. Sustainable SOC-management is becoming increasingly important especially in a context of climate change, since SOC-rich soils are more resilient to e.g. heavy rainfalls or drought periods. The pioneering spirit of SOC-certificate activities initiated world-wide can be of high value for the overall goal of fostering climate-smart agriculture and improving soil fertility. As long as SOC-certificates are not state-funded, farmers are free to 'sell' their achievements and to engage within local initiatives as part of their business operations.

The SOC-certificates could be kept exclusively as private sector initiatives and denoted 'Verified Emission Reductions for Voluntary Climate Action', which would require a more flexible interpretation of additionality. This would be in-line with similar initiatives, such as MoorFutures (2020), which are used for offsetting GHG-emissions of individuals, organisations or businesses according within corporate social responsibility schemes or similar. However, private SOC-initiatives might aim to expand to a broader scale, e.g. $CO_2$-compensation of flights or of large companies. To cope with this, the EU and its member states would need a policy decision on new mechanisms defining the relation between GHG-mitigation outcomes from private SOC-certification and national GHG-targets and accounting. Regarding the additionality of private SOC-certificates under the Paris Agreement, we recommend establishment of a new approach whereby countries, businesses and citizens take joint responsibility for national GHG-mitigation targets and welcome pioneering new activities.

Overall, our view is that separating private SOC-certificates properly from national GHG-reporting and accounting towards mitigation targets is very difficult. We advise governments not to interfere or provide financial support for private initiatives, but closely monitor their success and the ideas emerging. Governments could thereby identify opportunities for funding and establishing infrastructures for SOC-analysis and a SOC-audit scheme used by farmers and advisory services supporting 'C-neutral farming', or for building-up a network of farms to enhance communication and training on SOC-increasing activities.

## REFERENCES


Blanco-Canqui H, Lal R (2007) Soil structure and organic carbon relationships following 10 years of wheat straw management in no-till. Soil Till Res 95(1–2):240–254, doi:10.1016/j.still.2007.01.004

CarboCert (2020) [online]. Retrieved from <https://www.carbocert.de/> [at 23 March 2020]

Carbon Farmers of Australia (2020) [online]. Retrieved from <https://carbonfarmersofaustralia.com.au/> [at 26 March 2020]

Demenois J, Torquebiau E, Arnoult MH, Eglin T, Masse D, Assouma MH, Blanfort V, Chenu C, Chapuis-Lardy L, Medoc J-M, Sall SN (2020) Barriers and strategies to boost soil carbon sequestration in agriculture. Front Sustain Food Syst 4:37, doi:10.3389/fsufs.2020.00037

European Parliament and the Council of the European Union (2018) Regulation (EU) 2018/841 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU [online]. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0841-&from=EN> [at 23 March 2020]

Forstner S (2019) Humusaufbau und Zertifikathandel am Beispiel der Ökoregion Kaindorf [online]. Retrieved from <https://www.3-n.info/media/4_Downloads/pdf_NwsTrmn_3NVrnstltng_CarbonFarming_Hannover_Forstner.pdf> [at 10 July 2020]

Gold Standard (2020) [online]. Retrieved from <https://www.goldstandard.org/impact-quantification/certified-sdg-impacts> [at 26 March 2020]

Jacobs A, Flessa H, Don A, Heidkamp A, Prietz R, Dechow R, Gensior A, Poeplau C, Riggers C, Schneider F, Tiemeyer B, et al. (2018) Landwirtschaftlich genutzte Böden in Deutschland – Ergebnisse der Bodenzustandserhebung. Braunschweig: Johann Heinrich von Thünen-Institut, 316 p, Thünen Rep 64, doi:10.3220/REP1542818391000

Kätterer T, Bolinder MA, Andrén O, Kirchmann H, Menichetti L (2011) Roots contribute more to refractory soil organic matter than above-ground crop residues, as revealed by a long-term field experiment. Agric Ecosyst Environ 141(1–2):184–192, doi:10.1016/j.agee.2011.02.029

Kell DB (2012) Large-scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: why and how. Philos Trans R Soc Lond B Biol Sci 367(1595):1589–1597, doi:10.1098/rstb.2011.0244

Kollmuss A, Zink H, Polycarp C (2008) Making sense of the voluntary carbon market. A comparison of carbon offset standards [online]. Retrieved from <http://mobil.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/A_Comparison_of_Carbon_Offset_Standards_lang.pdf> [at 31 March 2020]

Lal R (2019) Conceptual basis of managing soil carbon: Inspired by nature and driven by science. J Soil Water Conserv 74(2):29A–34A, doi:10.2489/jswc.74.2.29A

Maillard É, Angers DA (2014) Animal manure application and soil organic carbon stocks: a meta-analysis. Glob Change Biol 20(2):666–679, doi:10.1111/gcb.12438

Merante P, Dibari C, Ferrise R, Sánchez B, Iglesias A, Lesschen JP, Kuikman P, Yeluripati J, Smith P, Bindi M (2017) Adopting soil organic carbon management practices in soils of varying quality: Implications and perspectives in Europe. Soil Till Res 165:95–106, doi:10.1016/j.still.2016.08.001

Minasny B, Malone BP, McBratney AB, Angers DA, Arrouays D, Chambers A, Chaplot V, Chen Z-S, Cheng K, Das BS, Field DJ, et al. (2017) Soil carbon 4 per mille. Geoderma 292:59–86, doi:10.1016/j.geoderma.2017.01.002

Ministère de la Transition Ècologique et Solidaire (2020) Label bas-carbone: récompenser les acteurs de la lutte contre le changement climatique [online]. Retrieved from <https://www.ecologique-solidaire.gouv.fr/label-bas-carbone> [at 30 June 2020]

MoorFutures (2020) [online]. Retrieved from <https://www.moorfutures.de/> [at 26 March 2020]

ÖkoregionKaindorf (2020) [online]. Retrieved from <https://www.oekoregion-kaindorf.at/> [at 23 March 2020]

Pellerin S, Bamière L, Angers D, Béline F, Benoit M, Butault JP, Chenu C, Colnenne-David C, De Cara S, Delame N, Doreau M, et al. (2017) Identifying cost-competitive greenhouse gas mitigation potential of French agriculture. Environ Sci Policy 77:130–139, doi:10.1016/j.envsci.2017.08.003

Poeplau C, Don A, Vesterdal L, Leifeld J, Van Wesemael B, Schumacher J, Gensior A (2011) Temporal dynamics of soil organic carbon after land-use change in the temperate zone – carbon response functions as a model approach. Glob Change Biol 17(7):2415–2427, doi:10.1111/j.1365-2486.2011.02408.x

Saj S, Torquebiau E (2018) Climate-smart agriculture, agroecology and soil carbon: towards winning combinations. Montpellier:Cirad. Perspective 47:1–4, doi:10.19182/agritrop/00034

Smith P (2004) Carbon sequestration in croplands: the potential in Europe and the global context. Eur J Agron 20(3):229–236, doi:10.1016/j.eja.2003.08.002

Smith P (2016) Soil carbon sequestration and biochar as negative emission technologies. Glob Change Biol 22(3):1315–1324, doi:10.1111/gcb.13178

Stevens A, van Wesemael B (2008) Soil organic carbon dynamics at the regional scale as influenced by land use history: a case study in forest soils from southern Belgium. Soil Use Manage 24(1):69–79, doi:10.1111/j.1475-2743.2007.00135.x

Stevens A, van Wesemael B, Bartholomeus H, Rosillon D, Tychon B, Ben-Dor E (2008) Laboratory, field and airborne spectroscopy for monitoring organic carbon content in agricultural soils. Geoderma 144(1–2):395–404, doi:10.1016/j.geoderma.2007.12.009

Stoessel F, Juraske R, Pfister S, Hellweg S (2012) Life cycle inventory and carbon and water foodprint of fruits and vegetables: application to a swiss retailer. Environ Sci Techol 46(6):3253–3262, doi:10.1021/es2030577

Sudmeyer RA, Daniels T, Jones H, Huxtable D (2012) The extent and cost of mallee–crop competition in unharvested carbon sequestration and harvested mallee biomass agroforestry systems. Crop Pasture Sci 63(6):-555–569, doi:10.1071/CP12129

Thamo T, Pannell DJ (2016) Challenges in developing effective policy for soil carbon sequestration: perspectives on additionality, leakage, and permanence. Clim Policy 16(8):973–992, doi:10.1080/14693062.2015.1075372

Thünen Institute (2020a) [online] Retrieved from <https://www.thuenen.de/en/wo/projects/soil-protection-and-forest-health/projekte-bodenzustandserhebung/national-forest-soil-inventory-in-germany-data-quality-and-data-management/> [at 20 Nov 2020]

Thünen Institute (2020b) [online] Retrieved from <https://www.thuenen.de/en/ak/projects/agricultural-soil-inventory-bze-lw/> [at 20 Nov 2020]

United Nations (1998) Kyoto protocol to the United Nations framework convention on climate change [online]. Retrieved from <https://unfccc.int/resource/docs/convkp/kpeng.pdf> [at 03 Apr 2020]

United Nations (2015) Paris agreement [online]. Retrieved from <https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf> [at 03 Apr 2020]

Valatin G (2012) Additionality and climate change mitigation by the UK forest sector. Forestry J For Res 85(4):445–462, doi:10.1093/forestry/cps056

von Lützow M, Kogel-Knabner I, Ekschmitt K, Matzner E, Guggenberger G, Marschner B, Flessa H (2006) Stabilization of organic matter in temperate

soils: mechanisms and their relevance under different soil conditions – a review. Eur J Soil Sci 57(4):426–445, doi:10.1111/j.1365-2389.2006.00809.x
Wesseler S (2020) Startups aim to pay farmers to bury carbon pollution in soil [online]. Retrieved from <https://www.yaleclimateconnections.org/2020/01/startups-aim-to-pay-farmers-to-bury-carbon-pollution-in-soil/> [at 23 March 2020]
Wiesmeier M, Mayer S, Paul C, Helming K, Don A, Franko U, Steffens M, Kögel-Knabner I (2020) $CO_2$-Zertifikate für die Festlegung atmosphärischen Kohlenstoffs in Böden: Methoden, Maßnahmen und Grenzen. BonaRes Series 2020/1, doi:10.20387/BonaRes-F8T8-XZ4H
Zero Foodprint (2020) [online, formerly the Perennial Farming Initiative] Retrieved from <https://www.zerofoodprint.org/about> [at 4 Nov 2020]
4 per Mille (2020). Welcome to the "4per1000" initiative [online]. Retrieved from <https://www.4p1000.org/> [at 30 June 2020]

 

POSITION PAPER

# Who is the subject of agroecological transitions? Local Agroecological Dynamisation and the plural subject of food systems transformation

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Received: March 31, 2020
Revised: August 26, 2020
Accepted: October 28, 2020

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KEYWORDS **agroecology, sustainability transitions, Local Agroecological Dynamisation, participatory action-research, scaling agroecology**

## 1 Introduction: agroecological transitions, for whom?

Having evolved from its roots in agricultural science, agroecology has in recent years been contributing methodologies, reflections and experiences for the development of sustainable food systems from a point of view of radical democracy (Gliessman, 2016). It is thus that social and political aspects have taken centre stage in agroecology in recent years, at the same time as it has gone from being a marginal approach to an "immaterial territory in dispute", claimed by national governments and large global institutions as much as by worldwide, grassroots organisations such as 'La Vía Campesina' (Giraldo and Rosset, 2017). This dispute, brought about by the mainstreaming of agroecology, entails risks of co-optation by international institutions (Rivera-Ferre, 2018). This is the context in which the agroecological movement has been carrying out its debate on the scaling of agroecological practices, and on the risks of the movement's institutionalisation possibly lending itself to conceptual co-optation and to the associated loss of its transformative features (Levidow et al., 2014; Giraldo and Rosset, 2017). The debate is still on the table, but it has made advances and has opened a new field of research focused on new experiences and knowledge that results when trying to apply agroecology at the food system scale (González de Molina et al., 2019).

The scaling of agroecological experiences has been conceptualised largely as following two paths that lead in different directions and that are often presented as being mutually exclusive. On the one hand is the path of 'out-scaling', referring to the process by which the agroecological transition extends over a territory, involving a growing number of social groups (with emphasis on the protagonism of the so-called "peasants") and promoting changes in food production, distribution and consumption practices (Giraldo and Rosset, 2017; Val et al., 2019). On the other hand is the path of 'up-scaling', oriented towards gaining political agency, the development of favourable political conditions for agroecology, fostering the institutionalisation of experiences and the development of public policies to protect, strengthen and enhance them – which are often conceived "from the top-down". This second path carries a high risk of significantly losing the political principles of agroecology (Mier y Terán et al., 2018; Ferguson et al., 2019). More recently, these two paths have been presented as being complementary and interconnected (Ferguson et al., 2019). From this perspective of convergence, the expansion or 'scaling' of agroecology would imply radical changes in the dominant agricultural system, especially in

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terms of incorporating "bottom-up" political approaches and the control of food systems by local communities – especially by those in the primary sector (Giraldo and McCune, 2019; González de Molina et al., 2019).

The expansion of agroecology is understood not only as the dissemination of a set of agricultural practices, but also as the expansion and strengthening of a socio-economic fabric capable of producing alternative food systems (Gliessman, 2016). This would foster interlinking agroecological experiences of production, distribution and consumption in a socio-political movement capable of acting at different territorial scales, within a transformative political project committed to overcoming capitalism, patriarchy and colonialism, and incorporating the contents of what has been called 'political agroecology' (Levidow et al., 2014; González de Molina et al., 2019). The objective of political agroecology would be the development of agroecology-based local agri-food systems that would then be promoted through two parallel action frameworks. On the one hand, out-scaling would promote the multiplication, strengthening and interconnection of local agroecological experiences (be they of food production, distribution or consumption; research; social and professional organisations; etc.). On the other hand, up-scaling would promote the development of a political and regulatory context favourable to the agroecological transition.

Although these two dimensions of agroecology scaling are extensively linked (Ferguson et al., 2019), I will focus on agroecology out-scaling, and more specifically on the theoretical and methodological problems arising from the emergence of social subjects to promote the scaling of agroecological experiences to food systems transformations. The expansion of the agroecological transition throughout a given territory, involving a growing number of social groups and producing changes in food production, distribution and consumption practices, has been tied to the emergence of the protagonism of 'peasants' and the so-called 'agroecological peasantry', as an historical and political (global and meta-) subject for the materialisation of the political project of La Vía Campesina (Val et al., 2019). However, the concept of "peasants" and "peasantries" remains controversial and contested, between being an analytical concept or a political category (Bernstein, 2010; McMichael, 2016).

Additionally, the number of holdings of different types of peasants, family farmers and small farmers around the world are still the majority but always decreasing, especially in metropolitan settings and urbanised societies (Graeub et al., 2016). For this reason, recent discussions underline the need to build plural and diverse social subjects that bring together agricultural and non-agricultural, rural and urban actors to undertake the agroecological transition at the food system scale (Edelman et al., 2014; Giraldo and McCune, 2019). This, however, does not forsake the necessary protagonism of farmers, and specially of the farmers' organisations closest to agroecology in such processes (Levidow et al., 2014; Giraldo and Rosset, 2017).

As agroecology is an action-oriented approach to do 'science with people', agroecological transitions cannot be done without a clear protagonism of farmers (Cuéllar and Calle, 2011), especially in an urbanised world in which both the rural reality and the specificities of the socio-ecological metabolism of food systems are getting increasingly hidden. In the present paper I will use the broad category of 'small farmers' to talk about 'agroecological peasantries' (Val et al., 2019), 'new peasants' (van der Ploeg, 2010) and the highly differentiated category of 'family farmers' (Bernstein, 2010), as protagonists of agroecological transitions at the food system scale.

In the present paper I use the term 'subject' as a socio-historical category to name an actor or network of actors committed to promote a specific (political and territorialised) project of transformation (Bernstein, 2010; Val et al., 2019). The proposition of a plural subject (bringing together differentiated actors) of the agroecological transition poses several challenges. On the one hand, in order to multiply experiences, it is necessary to attract the conventional farmers sector to agroecology – because they possess the means of production, but also because they need a change of model (van der Ploeg, 2010). On the other hand, among the diversity of actors involved are some that have so far been absent in the development of alternative food systems or agroecological transitions, specially in Global North settings – such as marginalised social groups or racial and cultural minorities (Simón-Rojo, 2019). In other cases, actors may come from local configurations with deep-rooted historical conflicts – such as between small food retailers and local farmers (López-García et al., 2018a). Such complexity within the subject of agroecological transitions, especially in deagrarianised societies, requires specific approaches. Often various tools and processes need to be adapted to the different profiles found in each territory (Guzmán et al., 2013; Menconi et al., 2017).

With this article I intend to provide some theoretical and methodological insights on how to promote food system scale agroecological transitions in settings where the agricultural social fabric is weak, and in general addressing the condition of a social subject highly differentiated worldwide. Assuming that 'small farmers' are to be the protagonist subject of agroecological transitions, I address several issues posed by the challenging construction of such a subject, allied with other social actors in what I call the plural subject of agroecological transitions, specially in urban and deagrarianised societies such as in Europe. The following sections cover three main objectives:

- to analyse critically different dimensions of the differentiated (social) subject of the transitions, with regard to current scientific debates on scaling agroecology (Section 2);
- to propose the Local Agroecological Dynamisation (LAeD) approach as a methodology for activating agroecological transition processes by integrating the difficulties posed by a complex plural subject (Section 3);
- and to discuss some lessons learned, based in case studies from Spain, that mainly involve conventional small farmers in sustainability transition processes, in order to define such a plural subject and provide some insights on how to construct its protagonism in deagrarianised settings (Section 4).

## 2 The social subject of agroecological transitions at the food system scale

It becomes increasingly difficult to speak of "peasantry" in growing portions of the planet, and in many territories the farming sector is profoundly weak and dependent on the corporate food regime (Bernstein, 2010; McMichael, 2016). Throughout the 20th century and before, the growing portions of the peasantry entering the (capitalist) market economy required the creation of new categories of analysis to address the differentiation process of the agricultural social subject (van der Ploeg, 2010; Bernstein, 2010). It becomes ever more difficult to consider it a homogeneous subject, as it is crossed by numerous contradictions that affect its capacity for action (Holt-Giménez and Shattuck, 2011). Meanwhile, agroecological experiences of production, distribution and consumption often adopt both conventional and alternative elements in their development, indistinctly and in a sequential and/or combined way, to achieve social and economic viability within alternative food networks or systems. These have been called hybrid actors and networks (Ilbery and Maye, 2005; Darnhofer, 2014).

The challenges for the agroecological transitions go beyond ecological processes at the farm scale, and encompass global processes that also cut across the conventional agricultural sector: from the degradation of traditional agricultural infrastructure and institutions, to global trade agreements, diet change or climate change. These problems, which are common to both conventional and alternative actors, could constitute shared platforms of action that also include non-agricultural actors (Holt-Giménez and Shattuck, 2011; Menconi et al., 2017). This potential should not be overlooked. The bulk of agri-food experiences that must be embraced by agroecology out-scaling are obviously small and medium-size conventional ones – since these constitute the majority and have a need to move towards alternative models – in addition to those that already follow agroecological models.

In this sense, hybrid actors are called upon to play an important role in the transition, due to their potential to broaden the social base of the processes, and to build bridges and alliances between conventional profiles and others closer to agroecology (López-García et al., 2018b). On the other hand, the sometimes exclusive pre-eminence that is given to agricultural and peasant experiences subtracts a social base from an agroecological movement that is already as urban as it is rural, leaving out other actors that are essential to making change possible (Tornaghi and Dehaene, 2019). This is especially the case in territories of the Global North, where agricultural and rural social fabrics are weak, and where it is therefore necessary to build alliances, perhaps tactical ones, with deeply conventional actors and alternative non-agricultural actors with links to food consumption, or with urban social movements (see, for example: Holt Giménez and Shattuck, 2011). With respect to the agroecologies of the Global South, while emphasizing their leaps of scale on the capacity of peasant and rural organisations to strengthen, multiply and territorialize themselves, they also express the need for much broader social alliances (Mier y Terán et al., 2018; Giraldo and McCune, 2019).

Thus, the social subject of agroecological transitions at the food system scale would have to be a plural subject, protagonised by farmers already aligned with agroecological approaches – perhaps the so-called 'agroecological peasantry'. These groups at the forefront provide the tractive force pulling conventional farmers, who make up the majority of the world's agricultural sector, especially in the Global North and in more urbanised territories. Incidentally, conventional farmers are demanding production and marketing models that are more sustainable and require less investment and debt (van der Ploeg, 2010). In an outer circle still forming part of this plural subject, we can find non-agricultural actors, who in turn are in need of new economic and territorial models beyond capitalism. On the one hand we have the agroecological social movement, which in Global North is mostly urban and composed of grassroots groups, NGOs, and networks of community and concerned consumers (Holt-Giménez and Shattuck, 2011; Tornaghi and Dehaene, 2019). On the other hand we have social groups excluded by the corporate food regime and cut off from markets (as is the case of small, traditional food retailers) or from adequate food (Simón-Rojo, 2019).

The complexity of this plural and heterogeneous subject raises new questions in the discussion on how to deal with it. Methodological arranges for constructing such a subject require dispositives (Val et al., 2019) to manage the divergent interests, symbolic worlds and velocities to step the transition. Specially regarding to a scheme where small farmers are to be protagonists and tractors of a broader space which includes urban and non-agricultural actors. These are developed in the following section.

## 3 Local Agroecological Dynamisation as a strategy to build plural and territorialised subjects

In recent decades, different methodological approaches for doing science with the people have been developed around agroecology, from an epistemological position committed to the transformation of reality (Gliessman, 2016). This methodological stance is in line with participatory action research (PAR) (Fals-Borda, 1991), since it is a research approach that produces knowledge that is both scientific (universal) and popular (situated); while, at the same time, it activates social processes of community empowerment from the perspective of popular education (Freire, 2012). From among the repertoire of participatory methodological proposals that have been linked to the agroecological approach, the following can be highlighted: participatory rural appraisal, participatory on-farm research, the Campesino a Campesino (peasant-to-peasant) movement, participatory action research, and LAeD (Guzmán et al., 2013, Méndez et al., 2017).

The transition from industrialised systems to agroecological systems requires specific extension practices. These must be adapted to a completely different farming system through a collective process of individual and social learning (Méndez et al., 2017). Farmers recognise the agroecological transitions as a complex process that links different spatial scales, and that is affected by multi-dimensional factors (Guzmán et al., 2013). Therefore, a complex approach is required that links and coordinates the ecological and productive aspects of agroecological approaches with others that appear at broader territorial scales. This should address issues such as the sustainability and social reproduction of rural communities or the power imbalances that cut across food systems, from the local to the global scale. In this sense, the epistemological stance taken by agroecology proposes to do science with and for the people, and argues that it is the social subject under investigation the one who must define the purpose and objectives of the research, as well as the forms it takes and how it evolves in each situation, in line with the proposals of popular education (Freire, 2012).

The Local Agroecological Dynamisation (LAeD) approach has been developed with regard to such international, both scientific and activist debates during the last few years. It is an application of participatory action-research to the agroecological perspective, to promote sustainability at local food systems level (López-García et al., 2018b). This methodology tries to apply theoretical and methodological approaches developed mainly in the Global South to deagrarianised settings such as the Global North or metropolitan territories worldwide. It mobilises the networks, resources and capacities of local communities through the revival of local agricultural production, farmers social protagonism and self esteem, traditional ecological knowledge, and alternative food networks. To this end, it links participatory action research with other methods of community research and development, in order to improve the capacities of local communities to build transitions to sustainability. This approach has been developed in Spain principally through several doctoral theses produced within the PhD program in agroecology at the International University of Andalucia (Guzmán et al., 2013), deeply connected with Latin America's agroecology movement; and since 2014 it has been developed further as part of the postgraduate diploma in 'Local Agroecological Dynamisation' at the Autonomous University of Barcelona, covering a greater breadth and diversity of cases. In the latter institution, research has been carried out through student field work, in collaboration with public and private entities (López-García et al., 2018b).

LAeD places special emphasis on generating collective processes of action-reflection-action, capable of overcoming the adherence to hegemonic discourses on behalf of actors who are expulsed from globalised economic flows (Freire, 2012). Special importance is given to the collaboration of hybrid actors that are capable of connecting conventional and alternative actors in networks of communication and cooperation (López-García et al., 2018b). This facilitates the progressive development of social and ecological sustainability innovation through participatory and multi-actor processes, which are open-ended and non-deterministic, and in which the paths of the transition are built through action, reflection and the empowerment of local actors. The territorialisation of processes – and of methodological tools – allows the construction of convergent processes based on the divergent interests, perceptions and positions of local actors, building transdisciplinarity (Lamine et al., 2019). Such multi-actor approach thus enhance the possibility of the construction of plural subjects, but requires a long period of time and therefore it is highly dependent on extended funding or social support.

The flexibility of the agroecological approach enables the construction of processes in which local communities are the protagonists in the analysis of their own reality and in the construction of development paths that offer an alternative to the corporate food regime. Transition paths, thus defined, have no predetermined end purpose – as could be the conversion to organic farming, for instance. Instead, the agroecological transition is understood as an open-ended and continuous process (Magda et al., 2019). One that can place greater or lesser emphasis on each of the transition's dimensions: environmental, social, economic, cultural or political; but which will always seek increasing levels of sustainability in local food systems, from a holistic perspective (Méndez et al. 2017). With this multiplicity of paths it is possible to accommodate very differentiated farmers and agri-food entrepreneurs profiles in the agroecological transitions; and to build alliances with other actors on a wide range of topics (for example, at-source price reductions, specific pests, or conflicts over agricultural land use) around the political project of food systems transformation (Holt-Giménez and Shattuck, 2011; Edelman et al., 2014; Val et al., 2019; Van Dyck et al., 2018). On the basis of partial alliances and community processes of empowerment around specific problems, it is possible to activate processes of action-reflection-action that lead to holistic transformations in the models of production, commercialisation and consumption within a given territory. In this way, open-ended participatory processes enable working with the plural and complex subject of agroecological transitions.

## 4 Some insights into the social subject of agroecological transitions in conventional agricultural structures

I conclude that there is a wide range of contexts worldwide where 'small farmers' are disorganised and weak in political terms, and thus show a limited agency to promote agroecological transitions by themselves. Specially in highly urbanised societies (in Global North, but not only) and metropolitan settings (also in Global South), we can see the emergence of plural subjects committed to promote food systems level agroecological transitions, involving rural and urban experiencies, agricultural and non-agricultural actors, and often with a strong role of researchers (among others Méndez et al., 2017; Van Dyck et al., 2018). As far as agroecology is a multidimensional concept, its development requires bringing together very diverse approaches and social profiles, as proposed by Edelman et al. (2014) for food sovereignity. Such plural social subjects comprises consumers, NGOs and also social groups and experiences included within the so-called 'urban agroecology' movement (Tornaghi and Dehaene, 2019).

This plural subject is showing a strong potential to foster agroecological transitions, involving a broad range of differentiated farmers' profiles, and specially supporting conventional (small) farmers to step on the transition process. Such plural subject should be based on the protagonism of small farmers as the ones who better know the real-world challenges for agroecological transitions and who assume the bigger risks for it. In this sense, the so-called 'agroecological peasantry', where existing, could be a core group within such plural subject. But, its absence, weakness or disconnection from mainstream farmers in a broad range of territorial contexts shows the need to construct (agroecological) territorialised farmers' organisations as a first step, in order to link such plural subject to the ground (both in material and immaterial terms). On the construction process of such a plural subject, the dispositives (sets of concepts, actions and possibilities, in terms of Val et al. (2019)) and methodologies used should be adapted to the different profiles of social actors involved in it. LAeD processes carried out in Spain, beside other participatory action research approaches developed worldwide (Mier y Terán et al., 2018) have shown a good performance to construct such a plural subject, and the protagonism of small farmers at its core. The development of a favourable policy and regulatory environment, through bottom-up processes pushed by such a social subject, might be also a key (but contradictory) question in order to scale agroecological transitions to food system level (Giraldo and McCune, 2019).

In recent years, various LAeD processes have been carried out in different territorial (rural, peri-urban and metropolitan) contexts in Spain in order to promote territorialised agroecological transitions with professional, conventional farmers, some of which have led to publications (among others: Guzmán et al., 2013; López-García et al., 2018b). From these Spanish experiences, in contrast with other scientific literature from diverse contexts, I can draw some conclusions concerning elements that are useful when promoting agroecological transitions in different contexts. This section presents the main lessons obtained with regards to the construction of the subject of agroecological transitions in different contexts and situations, through PAR processes.

The first element has to do with the degree of development of the agroecological transition in a given territory (Guzmán et al., 2013). For example, in territories with greater symptoms of deagrarianization (highly extensified and grants-dependent crops, older average age of farmers, high dependency on a market they do not control) farmers prefer to talk about issues that are on the margins of agricultural production: crop robberies, degradation of irrigation infrastructure, marketing channels, etc. Professional self-esteem is low, both individually and collectively (Kindon et al., 2007). Farmers here ask for help with these peripheral problems, because they do not consider themselves capable of effecting changes to their reality on their own. The way to engage actors in participatory processes – the strong point of the agroecological approach – is often by addressing issues that have to do with social reproduction and agricultural activity (new entrants into farming, farm transfers, farmers' collective action and agency, etc.), in which it may be easier to work through multi-actor schemes that include local, non-agricultural actors (Menconi et al., 2017).

In contrast, with farmers' profiles or in territories where agriculture is more profitable and capital-intensive, farmers are interested in meeting to improve their farming techniques; or to explore marketing channels at a higher price on a more conventional approach to transitions (Magda et al., 2019). In these contexts of business agriculture, people are not willing to spend much time on reflecting if it does not have a practical and immediate objective related to the profitability of agriculture (Schattmann et al., 2015). In such settings it will be more appropriate to focus on processes of farmers (on-field) participatory research, and to collaborate with specialised actors (professional organisations, research centres, R&D and innovation, etc.). In these cases it may be easier to work from a vertical approach – exclusively involving alliances within the agri-food chain – rather than a horizontal approach – involving territorial alliances between agricultural and non-agricultural actors, depending on the topics to be addressed (Schattmann, 2015; Menconi et al., 2017).

As previously stated, the fragility and weakness of the agricultural social fabric makes it necessary to work on the agroecological transitions together with other local profiles. For this reason, in parallel to the construction of the collective agricultural subject, there has been a tendency to build a network of alliances around the process, involving local social groups – mostly from outside the agricultural sector (as neighbours associations in urban or peri-urban settings), although also incorporating some agrarian institutions, such as irrigation communities, Designation of Origin regulatory councils, or research centres (Menconi et al., 2017; Van Dyck et al., 2018). In this methodological blueprint, which I have called 'concentric circles', the process by which local small farmers constitute a collective subject is located at the core of a broader process of social mobilization and cohesion around a shared project of sustainability for the territory. Being at the core implies protagonism, but not exclusivity (Edelman et al., 2014; Val et al., 2019).

Within this design of concentric circles, I have observed that the different local non-agricultural actors do not follow homogeneous patterns of behaviour. For example, in metropolitan contexts it has been easy to interact with researchers, neighbourhood associations and other urban actors, perhaps because they understand the potential of peri-urban agriculture to activate and mobilise the local identity in a sustainability project (Peredo and Barrera, 2018; Van Dyck et al., 2018). Similarly, actors such as school family associations or small businesses that were initially unaware of these projects, responded with openness and a very good disposition to become involved once contacted. Other institutions in the field of agriculture (cooperatives, professional organisations, Protected Designation of Origin regulatory councils, etc.), each with their own interests in the territory that often diverge from those of the agroecological transitions, have not been easily attracted. Lastly, organisations and social movements more closely linked to agroecology and food sovereignty have not always shared the objective of working with the conventional farming sector, nor the methodological approach of giving this sector the protagonism in the transition, which could be related to the differentiation between radical and progressist actors proposed by Holt Giménez and Shattuck (2011).

The implications of defining a plural, heterogeneous and complex subject of the (territorialised) agroecological transitions poses challenges that must be faced through empirical work. Much remains to be done in different territorial contexts and with different types of agricultural structures, both in the Global North and South, and especially in broad territorial contexts where the complexity of transforming local food systems can be faced. Nevertheless, the preliminary results here presented lay out very promising lines of work, from the point of view of transdisciplinary research in agroecology.

## Acknowledgements

I would like to thank the contribution made to the discussion of some of the ideas set forth in this text by my colleagues in the project "Mans a l'Horta, dinamització de l'activitat agraria al municipi de València": Lluís Benlloch, Vanessa Calabuig, Piero Carucci, Nacho Díaz, Alba Herrero, Mireia López, Josep Manuel Pérez and Lola Vicente. I would also like to thank the three anonymous reviewers for their comments on the first draft of the paper, which have improved it sensitively. This paper has been written thanks to the support of the Fund for the Third Sector Grants from the Spanish Ministry of Ecological Transition (2020).

### REFERENCES

Bernstein H (2010) The class dynamics of agrarian change. Halifax: Fernwood Publishing, 142 p

Cuéllar-Padilla M, Calle-Collado A (2011) Can we find solutions with people? Participatory action research with small organic producers in Andalusia. J Rural Stud 27(4):372–383, doi:10.1016/j.jrurstud.2011.08.004

Darnhofer I (2014) Contributing to a transition to sustainability of agri-food systems: Potentials and pitfalls for organic farming. In: Bellon S, Penvern S (eds) Organic farming, prototype for sustainable agricultures. Dordrecht: Springer, 439–452, doi:10.1007/978-94-007-7927-3_24

Edelman M, Weis T, Baviskar A, Borras SM Jr, Holt-Giménez E, Kandiyoti D, Wolford W (2014) Introduction: critical perspectives on food sovereignty. J Peasant Stud 41(6): 911–931, doi:10.1080/03066150.2014.963568

Fals-Borda O (1991) Acción y conocimiento: cómo romper el monopolio con investigación – acción participativa. Santa Fé de Bogotá: CINEP, 232 p

Ferguson BG, Aldasoro Maya M, Giraldo O, Mier y Terán Giménez Cacho M, Morales H, Rosset P (2019) Special issue editorial: What do we mean by agroecological scaling? Agroecol Sustain Food 43(7–8):722–723, doi:10.1080/21683565.2019.1630908

Freire P (2012) Pedagogía del oprimido. Madrid: Siglo XXI, 192 p

Giraldo OF, McCune N (2019) Can the state take agroecology to scale? Public policy experiences in agroecological territorialization from Latin America. Agroecol Sustain Food 43(7–8):785–809, doi:10.1080/21683565.2019.1585402

Giraldo OF, Rosset PM (2017) Agroecology as a territory in dispute: between institutionality and social movements. J Peasant Stud 45(3):545–564, doi:10.1080/03066150.2017.1353496

Gliessman S (2016) Transforming food systems with agroecology. Agroecol Sustain Food 40(3):187–189, doi:10.1080/21683565.2015.1130765

González de Molina M, Petersen PF, Garrido Peña F, Caporal FR (2019) Political agroecology: Advancing the transition to sustainable food systems. Boca Ratón: CRC Press, 201 p

Graeub BE, Chappell MJ, Wittman H, Ledermann S, Bezner Kerr R, Gemmill-Herren B (2016) The state of family farms in the world. World Dev 87:1–5, doi:10.1016/j.worlddev.2015.05.012

Guzmán GI, López-García D, Román-Bermejo L, Alonso AM (2013) Participatory action research in agroecology: Building local organic food networks in Spain. Agroecol Sustain Food 37(1):127–146, doi:10.1080/10440046.2012.718997

Holt-Giménez E, Shattuck A (2011) Food crises, food regimes and food movements: rumblings of reform or tides of transformation? J Peasant Stud 38(1):109–144, doi:10.1080/03066150.2010.538578

Ilbery B, Maye D (2005) Alternative (shorter) food supply chains and specialist livestock products in the Scottish-English borders. Environ Plan A 37(5):823–844, doi:10.1068%2Fa3717

Kindon S, Pain R, Kesby M (2007) Participatory action research approaches and methods: origins, approaches and methods. In: Kindon S, Pain R, Kesby M (eds) Participatory action research approaches and methods. Chapter 2, London: Routledge, 9–18, doi:10.4324/9780203933671

Lamine C, Magda D, Amiot M-J (2019) Crossing sociological, ecological and nutritional perspectives on agrifood systems transitions: towards a transdisciplinary territorial approach. Sustainability 11(5):1–18, doi:10.3390/su11051284

Levidow L, Pimbert M, Vanloqueren G (2014) Agroecological research: conforming – or transforming the dominant agro-food regime? Agroecol Sustain Food 38(10):1127–1155, doi:10.1080/21683565.2014.951459

López-García D, Calvet-Mir L, Di Masso M, Espluga J (2018b) Multi-actor networks and innovation niches: university training for local Agroecological Dynamization. Agric Hum Values 36: 567–579, doi:10.1007/s10460-018-9863-7

López-García D, Pontijas B, González de Molina M, Delgado M, Guzmán-Casado GI, Infante-Amate J (2018a) Saltando de escala…¿ hacia dónde? El papel de los actores convencionales en los sistemas alimentarios alternativos. Ager 25:99–127, doi:10.4422/ager.2018.14

Magda D, Girard N, Angeon V, Cholez C, Raulet-Croset N, Sabbadin R, Salliou N, Barnaud C, Monteil C, Peyrard N (2019) A plurality of viewpoints regarding the uncertainties of the agroecological transition. In: Bergez JE, Audouin E, Therond O (eds) Agroecological transitions: From theory to practice in local participatory design. Cham: Springer, 99–120, doi:10.1007/978-3-030-01953-2_6

McMichael P (2016) Regímenes alimentarios y cuestiones agrarias. Barcelona: Icaria, 260 p

Menconi ME, Grohmann D, Mancinelli C (2017) European farmers and participatory rural appraisal: A systematic literature review on experiences to optimize rural development. Land Use Pol 60:1–11, doi:10.1016/j.landusepol.2016.10.007

Méndez VE, Caswell M, Gliessman SR, Cohen R (2017) Integrating agroecology and participatory action research (PAR): Lessons from Central America. Sustainability 9(5):705, doi:10.3390/su9050705

Mier y Terán Giménez Cacho M, Giraldo OF, Aldasoro M, Morales H, Ferguson BG, Rosset P, Khadse A, Campos C (2018) Bringing agroecology to scale: key drivers and emblematic cases. Agroecol Sustain Food 42(6): 637–665, doi:10.1080/21683565.2018.1443313

Peredo y Parada S, Barrera Salas C (2018). Democratizando el consumo ecológico: Elementos para la acción y aprendizaje colectivo en procesos de investigación acción participativa. Agroecología 13(1):57–69

Rivera-Ferre MG (2018) The resignification process of agroecology: Competing narratives from governments, civil society and intergovernmental organizations. Agroecol Sustain Food 42(6):666–685, doi:10.1080/21683565.2018.1437498

Schattman R, Méndez VE, Westdjik K, Caswell M, Conner D, Koliba C, Zia A, Hurley S, Adair C, Berlin L, Darby H (2015) Vermont agricultural resilience in a changing climate: A transdisciplinary and participatory action research (PAR) process. In: Benkeblia N (ed) Agroecology, ecosystems and sustainability. Boca Raton, Fl: CRC Press, 326–343

Simón-Rojo M (2019) Agroecology to fight food poverty in Madrid's deprived neighbourhoods. Urban Des Int 24(2):94–107, doi:10.1057/s41289-019-00088-4

Tornaghi C, Dehaene M (2019) The prefigurative power of urban political agroecology: rethinking the urbanisms of agroecological transitions for food system transformation. Agroecol Sustain Food 44(5):594–610, doi:10.1080/21683565.2019.1680593

Val V, Rosset PM, Zamora Lomelí C, Giraldo OF, Rocheleau D (2019) Agroecology and La Via Campesina: I. The symbolic and materialconstruction of agroecology through the dispositive of "peasant-to-peasant" processes. Agroecol Sustain Food 43(7–8):872–894, doi:10.1080/21683565.2019.1600099

van der Ploeg JD (2010) Nuevos campesinos. Campesinos e imperios alimentarios. Barcelona: Icaria, 430 p. Retrieved from <https://edepot.wur.nl/424202> [at 13 Nov 2020]

Van Dyck B, Vankeerberghen A, Massart E. Maughan N, Visser M (2018) Institutionalization of participatory food system research: Encouraging reflexivity and collective relational learning. Agroecología 13(1):21–32

POSITION PAPER

# Agroecological terroir: an approach for scaling-out local food systems

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Received: May 12, 2020
Revised: August 9, 2020
Accepted: August 25, 2020

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KEYWORDS **food systems, sustainability, agroecological practices, food quality**

## 1 Pathways to sustainable agriculture of tomorrow

At the beginning of the 21st century, agriculture copes with multiple challenges concerning global food security, while increasing population and consumption are placing unprecedented demands on agriculture and natural resources (Foley et al., 2011; Poore and Nemecek, 2018). Accordingly, food production remains a key pillar of food security (Porter et al., 2014) and a crucial point of intervention for food availability. The establishment of a global world market allows for increased availability of all types of food throughout the year, regardless of production season and region (Kearney, 2010). As a result, modern agriculture has the potential to provide more than enough food for a population reaching up to $10 \times 10^9$ people by 2050 (Searchinger et al., 2019). This contradicts the view that food security is dramatically compromised by the effects of global climate change (Lobell et al., 2011), the use of agricultural products for industrial purposes (von Braun, 2007), and animal feed (Salami et al., 2019). In addition to this, 70 % less arable land area was needed in 2014 to produce the same quantity of crops as in 1961; at the same time, the yield of major staple crop increased (Ritchie and Roser, 2020). Lappé et al. (1998) presented evidence that intensification in agriculture and a gradual increase in agricultural production could lead to further deterioration of the environment and depletion of non-renewable resources. Smith (2015) argues that instead of expanding the limits of food production, we need to manage demand, particularly that for livestock products if we want to meet food security in 2050. In addition, the developments of global food systems impose some consequences anticipated before but not properly managed, such as the concentration of power into multinational companies and the internationalisation of the market. Projections of the future of agriculture are based on our current knowledge, which in the global context often gives an insufficiently clear picture of what we can expect. Conditions that have not been considered so far will shape the future and considerably affect food security. Among them, the following challenges can be anticipated:

1. A new generation of consumers with specific requirements will emerge;
2. information communication technologies (ICT) will boost the global food market and allow for buying virtually anything from anywhere;
3. improved crops and livestock with specific traits adapted to the altered environment will be developed;
4. increased interest in palatable, ultra-processed foods (made from processed substances extracted or refined from whole foods), and new food sources, lab meat, algae, and insects;
5. continuous soil degradation will affect the capacity of our food system to meet the requirement of the global population;

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6. fewer farmers will be involved in food production, and agriculture will rely more on automatisation, robotics, and ICT.

Because of all this, the quest for solutions that would be globally acceptable and sustainable from an ecological and socio-economic point of view is the major task of contemporary agriculture (Odegard and van der Voet, 2014). According to Griggs et al. (2013), the future development of food systems largely relies on how successfully 17 sustainable development goals (SDGs) will be achieved (United Nations, 2015). The beginning of the 21st century has brought much greater interest in food production, consumption, as well as its nutritional properties. This has led to the popularisation of a different alternative concept of a local food system that symbolises a paradigm shift from the globalised and industrialised mainstream production. Recently, a large number of socio-economic and environmental movements converged around local food systems that refer to voluntarily established food systems characterised by a close producer-consumer relationship within a designated place or local area (Hall and Gössling, 2016). Accordingly, the combination of research-based innovations and traditional knowledge yields multiple options for transforming food systems at the local level (Caron et al., 2018). DuPuis and Goodman (2005) advocate that there is an increasingly important connection between the localisation of food systems and the promotion of environmental sustainability and social justice. The local modification of alternative food systems has resulted in short food chains (Kilometre Zero, box delivery schemes, urban agriculture) and the establishment of 'slow food' consumption. Such systems are characterised by a closer relation between local producers and consumers, better interaction between organisations and farmers, fair production conditions, and distinctive flavour and aroma of the produced food (Feldmann and Hamm, 2015). El Bilali (2019) stressed in a comprehensive review that the way forward for research on agro-food sustainability transitions implies a deeper understanding of different socio-technical system levels and landscape-niche-regime interactions. Garnett (2013) elaborated that the priority for the future is a nutrition-driven food system that remains within environmental limits. Adams and Salois (2010) argue that the demand for local food will largely arise in response to corporate co-optation of the organic food market and the introduction of the concept of "organic lite". Guthman (2014) presented a scenario involving this concept for California, in which big agribusinesses impose a model of farming practice adaptation (specialisation in high-value crops), thus leading to the conventionalisation of organic production. Some studies show that consumers tend to value the local origin of the product more than the organic nature of production (de-Magistris and Gracia, 2014; Campbell, 2014). As a result, a shift away from organic and toward local food in consumer preferences will bring new implications for the environment and society (Meas et al., 2014). Globally, the interest in locally produced foods is increasing, but it becomes very difficult for consumers to find it in mainstream shops (Hardesty, 2008). Wholesale and retail food buyers show increasing interest in purchasing locally produced foods; however, the consistency of supply, lower product volume, labelling and information about product origin are common barriers for their greater penetration into the conventional markets. Therefore, local and global food systems must be developed simultaneously and overlap in the pursuit of food security. This will require efforts to increase the environmental efficiency of food production, but this approach is not sufficient to achieve the sustainability of food systems (Capone et al., 2014). This paper seeks to contribute to the discussion about food system development with the encouragement of synergies between the terroir and agroecology.

## 2 Defining the position

The term 'terroir' has for a long time gained much attention in the context of viticulture (wine production) and has been extensively used in describing the "sense of place" derived from a complex interaction of climate, soil, tradition, geomorphology, and variety. The concept of terroir is frequently used to explain the sensory attributes of high-quality wines by the environmental conditions in which the grapes are grown (Seguin, 1988). Commonly, terroir is associated with adjusted methods of resource management that enhances the quality hierarchy of the final product and differs from similar products. Vaudour et al. (2015) elucidate that studies based on metabolomics or strontium isotopic ratio strengthen the assumption that geographical origin does leave an imprint on wines through soil substrate and climate and the interaction of viticulture choices. The same author noted that microbial terroir is identified as a key factor in variation among grapes growing in different locations. In addition, terroir is associated with specific management practices, not exclusively ecological (practices with a beneficial impact on the environment), that create a physical environment and connect production methods with sensory attributes and character of the end product.

Initially, terroir was recognised in the production of wine, olives, and cheese. Jacobsen (2010) was among the first to point out the wider potential of terroir as a local food quality concept. He wrote the first guide to the "flavour landscapes" of different foods, including apples, honey, maple syrup, coffee, oysters, salmon, wild mushrooms, wine, cheese, and chocolate. In France, using sourdough bread ecosystems as a model, Michel et al. (2017) documented that the microbial diversity associated with bread-making practices related with human and socio-cultural practices could give the bread a "sense of place". According to Turbes et al. (2016), the geographical location of the milk source has an effect on the flavour of Cheddar cheese, but the practices of milk commingling and heat treatment are likely to reduce the effect of geographical location, particularly as the cheese ages. In tea production, terroir is linked with the production ecosystem and the process of manual collection that workers themselves knowingly reproduce in the taste of the final product (Besky, 2014). On the contrary, critics argue that terroir comes into the fore with luxury consumption and the obtained products are intended only for wealthy customers; because of this, the concept has a restricted contribution to food security (Dagne, 2015).

To overcome the world's greatest challenges in food production/supply, agroecology has been proposed as a set of practices and people-centred knowledge, intensively and deeply rooted in sustainability (FAO, 2018a). Agroecological approaches are increasingly considered as possible alternatives to the industrial model of agricultural improvement, representing concrete transition pathways towards sustainable food systems that enhance food security and nutrition (HLPE, 2019). Many researchers support the idea that agroecology is a key tool in the transition to sustainable food systems (Gliessman, 2016; Hatt et al., 2016). Such systems involve agroecology, which in turn incorporates science, a set of practices, and a social dimension. Their co-evolution and supplementation develop a holistic approach to agriculture as a crucial driver in creating the foundation for environmentally sound food systems (Wezel et al., 2009; Gliessman, 2015). A crucial aspect of agroecological approaches is an increased reliance on knowledge and ecological management, complementing and reducing the use of external inputs. Today, agroecology is referred as a transdisciplinary concept that includes ecological, sociocultural, technological, economic, and political dimensions of food systems, from production to consumption (HLPE, 2019). Wezel et al. (2014) identified a wide range of agricultural practices and solutions that are agroecological in nature (organic fertilisation, reduced tillage, biological pest control, cultivar choice, crop rotation, direct seeding into living cover crops and mulch etc.). The combination of agroecological concepts with respectful utilisation of physical environment has the potential to ensure better valorisation of local food systems.

## 3 A conceptual encounter of agroecology and terroir

So far, 'terroir' has not been combined with 'agroecology', but bringing them together could empower local food systems by expanding synergies within the framework of agroecology and supporting advanced food quality. Although both approaches have existed simultaneously, there has been no overlap because the two concepts have contrasting ideas about food production and different groups of specialists have been interested in each of them. On the one hand, terroir is focused on the quality of the final product, while agroecology is focused on food production that conserves resources. The growing interest in local food production and sensibilised consumers represent the common ground for both of these concepts. Vast evidence suggests that the certification schemes of protected geographical origin under sustainable management have many complementary advantages across the globe compared to mainstream agriculture (Charters et al., 2017; FAO, 2018b). Gyimóthy (2017) reported that the potential of food place promotion has been extensively studied in the context of tourism and place branding as a strategic asset to raise awareness and create an image of local food in the consumer's mind.

Therefore, it is important to investigate what contribution to local food production systems would produce a combination of agroecology and terroir. The idea of combining terroir with agroecology has been proposed within the framework of promoting local food consumption and sustainable development (Šeremešić, 2019). Wezel et al. (2016) recognised the importance of territorial scale in agroecology and presented a similar approach for food systems and biodiversity conservation. The authors argued that the development of sustainable systems at a territorial scale was strongly neglected and are almost exclusively proposed either at the scale of specific agricultural systems or for selected supply chains. Surprisingly, when combined at the same production area, not many of the basic concepts of agroecology and terroir are overlapping (*Figure 1*). The terroir is a result of a complex interaction of climate, soil type, geomorphology, microbiota, water regime, variety history and cultural tradition (Meinert, 2018). This concept covers a wide range of activities but only a few address the social and ecological dimensions of resource management. On the other hand, agroecology is rooted in biodiversity, co-creation of knowledge, synergies, resilience, environmental protection, food sovereignty, social inclusiveness, adaptable management practices, and co-innovation (Wezel et al., 2014). The ten elements of agroecology, proposed by FAO (2019), and complemented with the recognition of geographical origin (van Leeuwen and Seguin, 2006), would possibly result in improved food quality from the development of agroecological terroir.

Agroecology is oriented towards maintaining the production resources and the application of practices that improve agroecosystem as a whole as well as the neighbouring natural systems. The implementation of a management system that is grounded in agroecology and combined with terroir physical environment could result in the development of a new food system with multiple benefits. The proposed system could be easily adapted to different

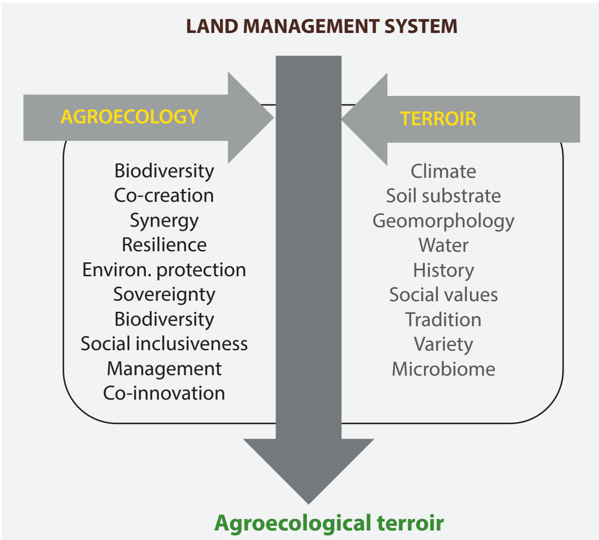


FIGURE 1
Transformation of land management systems with agroecological terroir

environments and socio-economic conditions shown in *Figure 2*. Accordingly, the benefit from terroir recognition under the schemes of agroecological practices would be more appealing for consumers compared to conventional production and could present a strategic option in the promotion of the local food systems. Starting from the point that each place on the Earth is physically unique and often coincides with a society marked by a common, indigenous outlook and way of life found nowhere else, Charters et al. (2017) elucidate that a place offers an advantage which others cannot reproduce and, in return, people must steward the integrity of that place to sustain its ability to create value. In California, agroecological partnerships are becoming the chief vehicle for extending sustainable agricultural practices, while "quality turn" has received attention from researchers for its potential to organise linkages among various forces in agro-food systems (Warner, 2007).

There is evidence to suggest the hypothesis that the food system transformation can be successful only when local organisations are able to develop and spread (i.e. scale-up and -out), without compromising the guiding principles of sustainability. Scaling-out implies that an innovation crosses the boundaries reaching more people, which in the context of the food systems means more consumers and producers (Pitt and Jones, 2016). Successful scaling-up relies heavily on enhancing human capital and empowering local communities through training and participatory methods that take into account farmers' requirements, aspirations, and traditions (Altieri and Nicholls, 2012). This is important because scaling-up bears the danger of co-optation and assimilation into the dominant food system (Laforge et al., 2017). Agroecological terroir could benefit from horizontal scaling-out with geographical spread through replication and adaptation and vertical scaling-up that implicates the institutional strengthening and involves different stakeholders from grassroots organisations to academia, NGO, policy-makers, and donors (Parmentier, 2014). Millar and Connell (2009) conclude that scaling-out positive impacts from systems change requires

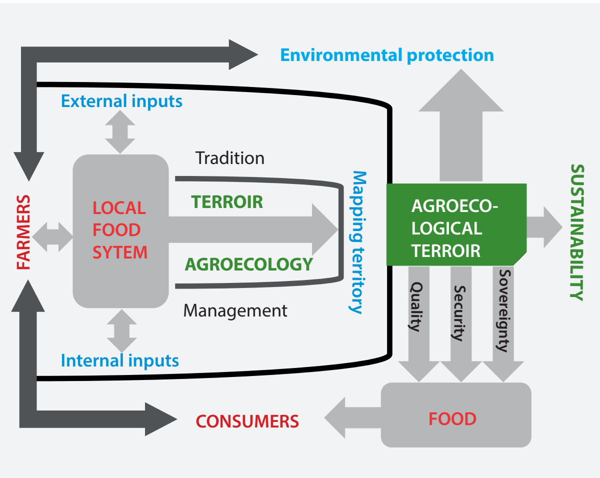


FIGURE 2
The positioning of agroecological terroir for the improvement of local food systems

field-tested and proven technologies, evidence of significant livelihood impacts, fostering of local innovation, competent field staff, effective peer learning, and ongoing institutional support. Consequently, agroecological terroir can gain recognition by using practices and methods that increase sustainability and reach more consumers. What is also important is that the presented concept can make a significant contribution to environmental protection (Belletti et al., 2015). It is particularly relevant that the concept of agroecological terroir could place a special value on the taste of food and can contribute to the "farm to fork strategy" of the EU (EC, 2019). In another context, it could help to strengthen local food systems and make them more identifiable and recognisable. Gliessman (2015) has proposed a framework for classifying "levels" of food system change. He advocates the scaling-up of agroecology and progressive development of sustainable food systems where local food schemes play an important role. Guzman et al. (2013) stressed that changes of individual technological procedure in the food system are not sufficient because it is necessary to change the agri-food system as a whole.

Although many advantages can be anticipated from the proposed concept of agroecological terroir, there will be some obstacles to its implementation. I believe that the preparation is crucial before we can establish a functional relationship between agroecology and terroir within a practical framework. The introduction of agroecological terroir will require tangible access to different agroecosystems due to complex interaction with the surrounding ecosystems. In the process of co-creation and scaling, there must be a clear goal for which agroecological terroir indicators should be set. Since agroecology is a broader concept than terroir, it would be necessary first to harmonise the dimension of science, rural movement, and practice and then co-create local food systems with terroir encompassing ecological, social, and economic dimensions. Some important trade-offs should be taken into consideration for appropriate decision making regarding agroecological terroir performance. This includes distinguishing who is "in" and who is "out" regarding the "standard" achievement, the balance between private and public coordination, economic vs environmental impact and assessment (FAO, 2018b). Therefore, the implementation of the agroecological terroir in improving the local food systems will need time and must be introduced with legislative support. Procedures can help to identify key elements and minimum requirements for the establishment of agroecological terroir as well as potential support for its introduction.

## 4 Conclusion

Agroecological terroir represents a new approach in valorisation of local food systems and the development of food quality recognition while preserving the production resources. This work suggests that the integration of terroir and agroecology could add a specific sensory and quality experience to agricultural products, while agroecological practices could provide environmental protection. In this context agroecological terroir creates a framework for scaling-out local food systems and make them more visible and appealing for consumers. For that reason, the benefit from agroecological terroir can be reproduced and could present a strategic option in the promotion of different agricultural regions and add a new experience in local food consumption. The present study emphasises the importance of the proposed agroecological terroir approach and its implication for a better understanding of sustainable food systems development in future.

## REFERENCES


Adams DC, Salois MJ (2010) Local versus organic: A turn in consumer preferences and willingness-to-pay. Renew Agr Food Syst 25(4):331–341, doi:10.1017/S1742170510000219

Altieri MA, Nicholls CI (2012) Agroecology scaling up for food sovereignty and resiliency. In: Lichtfouse E (ed) Sustainable agriculture reviews. Chapter 1. Dordrecht: Springer, 1–29, Sustainable sgriculture reviews, Vol. 11, doi:10.1007/978-94-007-5449-2_1

Belletti G, Marescotti A, Sanz-Cañada J, Vakoufaris H (2015) Linking protection of geographical indications to the environment: Evidence from the European Union olive-oil sector. Land Use Policy 48:94–106, doi:10.1016/j.landusepol.2015.05.003

Besky S (2014) The labor of *terroir* and the *terroir* of labor: Geographical indication and Darjeeling tea plantations. Agr and Hum Values 31(1):83–96, doi:10.1007/s10460-013-9452-8

Campbell BL, Khachatryan H, Behe BK, Dennis J, Hall C (2014) U. S. and Canadian consumer perception of local and organic terminology. Int Food Agribus Man 17(2):21–40, doi:10.22004/ag.econ.167903

Capone R, El Bilali H, Debs P, Cardone G, Driouech N (2014) Food system sustainability and food security: Connecting the dots. J Food Secur 2(1): 13–22, doi:10.12691/jfs-2-1-2

Caron P, Ferrero y de Loma-Osorio G, Nabarro D, Hainzelin E, Guillou M, Andersen I, Arnold T, Astralaga M, Beukeboom M, Bickersteth S, Bwalya M, et al. (2018) Food systems for sustainable development: proposals for a profound four-part transformation. Agron Sustain Dev 38:41, doi:10.1007/s13593-018-0519-1

Charters S, Spielmann N, Babin BJ (2017) The nature and value of terroir products. Eur J Mark 51(4):748–771, doi:10.1108/EJM-06-2015-0330

Dagne TW (2015) Beyond economic considerations: (Re)Conceptualizing geographical indications for protecting traditional agricultural products. IIC Int Rev Intellect Prop Compet Law 46:682–706, doi:10.1007/s40319-015-0377-1

de-Magistris T, Gracia A (2014) Do consumers care about organic and distance labels? An empirical analysis in Spain. Int J Consum 38(6):660–669, doi:10.1111/ijcs.12138

DuPuis EM, Goodman D (2005) Should we go "home" to eat? Toward a reflexive politics of localism. J Rural Stud 21(3):359–371, doi:10.1016/j.jrurstud.2005.05.011

El Bilali H (2019) The multi-level perspective in research on sustainability transitions in agriculture and food systems: A systematic review. Agriculture 9(4):74, doi:10.3390/agriculture9040074

EC, European Commission (2019) Towards a sustainable Europe by 2030. Reflection paper [online], doi:10.2775/676251

FAO (2018a) FAO's work on agroecology. A pathway to achieving the SDGs [online]. Rome: FAO, 28 p. Retrieved from <http://www.fao.org/3/I9021EN/i9021en.pdf> [at 31 July 2020]

FAO (2018b) Strengthening sustainable food systems through geographical indications [online]. Rome: FAO, 135 p. Retrieved from <http://www.fao.org/3/I8737EN/i8737en.pdf> [at 31 July 2020]

FAO (2019) The ten elements of agroecology [online]. Rome: FAO, 9 p, Council, 163rd Session, Document CL 163/13 Rev.1. Retrieved from <http://www.fao.org/3/ca7173en/ca7173en.pdf> [at 31 July 2020]

Feldmann C, Hamm U (2015) Consumers' perceptions and preferences for local food: A review. Food Qual Prefer 40(A):152–164, doi:10.1016/j.foodqual.2014.09.014

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, et al. (2011) Solutions for a cultivated planet. Nature 478:337–342, doi:10.1038/nature10452

Garnett T (2013) Food sustainability: problems, perspectives and solutions. Proc Nutr Soc 72(1):29–39, doi:10.1017/S0029665112002947

Gliessman S (2016) Transforming food systems with agroecology. Agroecol Sustain Food 40(3):187–189, doi:10.1080/21683565.2015.1130765

Gliessman SR (2015) Agroecology: The ecology of sustainable food systems, 3rd edition. Boca Raton, FL: CRC Press/Taylor and Francis Group, 406 p

Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I (2013) Sustainable development goals for people and planet. Nature 495(7441):305–307, doi:10.1038/495305a

Guthman J (2004) The Trouble with 'Organic Lite' in California: A rejoinder to the conventionalisation' debate. Sociol Rural 44(3):301–316, doi:10.1111/j.1467-9523.2004.00277.x

Guzmán GI, López D, Román L, Alonso AM (2013) Participatory action research in agroecology: Building local organic food networks in Spain. Agroecol Sustain Food 37(1):127–146, doi:10.1080/10440046.2012.718997

Gyimóthy S (2017) The reinvention of terroir in Danish food place promotion. Euro Plan Stud 25(7):1200–1216, doi:10.1080/09654313.2017.1281229

Hall CM, Gössling S (eds) (2016) Food tourism and regional development: Networks, products and trajectories. London: Routledge, 314 p, doi:10.4324/9781315691695

Hardesty SD (2008) The growing role of local food markets. Am J Agr Econ 90(5):1289–1295, doi:10.1111/j.1467-8276.2008.01219.x

Hatt S, Artru S, Brédart D, Lassois L, Francis F, Haubruge E, Garré S, Stassart PM, Dufrêne M, Monty A, Boeraeve F (2016) Towards sustainable food systems: the concept of agroecology and how it questions current research practices. A review. Biotechnol Agron Soc Environ 20(S1):215–224, doi:10.25518/1780-4507.12997

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]

Jacobsen R (2010) American terroir: Savoring the flavors of our woods, waters, and fields. New York: Bloomsbury Publishing USA, 288 p

Kearney J (2010) Food consumption trends and drivers. Phil Trans R Soc B 365: 2793–2807, doi:10.1098/rstb.2010.0149

Laforge JM, Anderson CR, McLachlan SM (2017) Governments, grassroots, and the struggle for local food systems: containing, coopting, contesting and collaborating. Agric Hum Values 34: 663–681, doi:10.1007/s10460-016-9765-5

Lappé FM, Collins J, Rosset P (1998) World hunger: 12 myths. 2nd edition. New York: Grove Press, 271 p

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333(6042):616–620, doi:10.1126/science.1204531

Meas T, Hu W, Batte MT, Woods TA, Ernst S (2014) Substitutes or complements? Consumer preference for local and organic food attributes. Am J Agr Econ 97(4):1044–1071, doi:10.1093/ajae/aau108

Meinert LD (2018) The science of terroir. Elements 14(3):153–158, doi:10.2138/gselements.14.3.153

Michel E, Debroise H, Deffrasnes M, Hue I, Guezenec S, Lebrat J, Legrand J, Goldringer I, Rousselot S, Serpolay-Besson E, et al. (2017) Impact of baker's practices, terroir and wheat varieties on sourdough microbial taxonomic and functional diversity [online]. Retrieved from <https://hal.archives-ouvertes.fr/hal-02154391> [at 30 Nov 2020]

Millar J, Connell J (2009) Strategies for scaling out impacts from agricultural systems change: the case of forages and livestock production in Laos. Agric Hum Values 27:213–225, doi:10.1007/s10460-009-9194-9

Odegard IYR, van der Voet E (2014) The future of food – Scenarios and the effect on natural resource use in agriculture in 2050. Ecol Econ 97:51–59, doi:10.1016/j.ecolecon.2013.10.005

Parmentier S (2014) Scaling-up agroecological approaches: what, why and how [online]. Brussels: Oxfam-Solidarity, 93 p. Retrieved from <http://www.fao.org/fileadmin/templates/agphome/scpi/Agroecology/Agroe-

cology_Scaling-up_agroecology_what_why_and_how_-OxfamSol-FINAL.pdf> [at 13 Nov 2020]

Pitt H, Jones M (2016) Scaling up and out as pathway for food system transitions. Sustainability 8:1025, doi:10.3390/su8101025

Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360(6392):987–992, doi:10.1126/science.aaq0216

Porter JR, Xie L, Challinor AJ, Cochrane K, Howden SM, Iqbal MM, Lobell DB, Travasso MI (2014) Food security and food production systems. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, et al. (ed) Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Cambridge: Cambridge University Press, 485–533

Ritchie H, Roser M (2020) Crop Yields [online]. Retrieved from <https://ourworldindata.org/crop-yields> [at 01 May 2020]

Salami SA, Luciano G, O'Grady MN, Biondi L, Newbold CJ, Kerry JP, Priolo A (2019) Sustainability of feeding plant by-products: A review of the implications for ruminant meat production. Anim Feed Sci Technol 251:-37–55, doi:10.1016/j.anifeedsci.2019.02.006

Searchinger T, Waite R, Hanson C, Ranganathan J (2019) Creating a sustainable food future: A menu of solutions to feed nearly 10 billion people by 2050 (Final report) [online]. Washington: World Resource institute, 564 p, Synthesis report. Retrieved from <https://files.wri.org/s3fs-public/wrr-food-full-report.pdf> [at 14 Nov 2020]

Seguin G (1988) Ecosystems of the great red wines produced in the maritime climate of Bordeaux. In: Fuller-Perrine L (ed) Proceedings of the Symposium on maritime climate winegrowing. Geneva, NY: Department of Horticultural Sciences, Cornell University, 36–53

Šeremešić S (2019) Agroecological terroir: empowering the local food system. In: Gkisakis V, Bellon S, Bàrberi P, Migliorini P, Peeters A, Wezel A (ed) Scaling out, moving forward! Proceedings of the 2nd Agroecology Europe Forum. Heraklion: Agroecology Europe, 26–28 Sept 2019, 23–24

Smith P (2015) Malthus is still wrong: we can feed a world of 9–10 billion, but only by reducing food demand. Proc Nutr Soc 74(3):187–190, doi:10.1017/S0029665114001517

Turbes G, Linscott TD, Tomasino E, Waite-Cusic J, Lim J, Meunier-Goddik L (2016) Evidence of *terroir* in milk sourcing and its influence on Cheddar cheese. J Dairy Sci 99(7):5093–5103, doi:10.3168/jds.2015-10287

United Nations (2015) Transforming our world: The 2030 Agenda for Sustainable Development. New York, NY: United Nations, 40 p. Retrieved from <https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf> [at 1 May 1, 2020]

van Leeuwen C, Seguin G (2006) The concept of terroir in viticulture. J Wine Res 17(1):1–10, doi:10.1080/09571260600633135

Vaudour E, Costantini E, Jones GV, Mocali S (2015) An overview of the recent approaches to terroir functional modelling, footprinting and zoning. Soil 1(1):287–312, doi:10.5194/soil-1-287-2015

von Braun J (2007) When food makes fuel: The promises and challenges of biofuels. Conference Biofuels, energy and agriculture: powering towards or away from food security, Canberra, Australia, 15 Aug 2007, 9 p, doi:10.22004/ag.econ.124488

Warner KD (2007) The quality of sustainability: Agroecological partnerships and the geographic branding of California winegrapes. J Rural Stud 23(2):142–155, doi:10.1016/j.jrurstud.2006.09.009

Wezel A, Bellon S, Doré T, Francis C, Vallod D, 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

Wezel A, Brives H, Casagrande M, Clément C, Dufour A, Vandenbroucke P (2016) Agroecology territories: places for sustainable agricultural and food systems and biodiversity conservation. Agroecol Sustain Food 40(2):132–144, doi:10.1080/21683565.2015.1115799

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

POSITION PAPER

# Why international agricultural research should draw on agroecology to support sustainable food systems

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Received: May 15, 2020
Revised: August 12, 2020
Accepted: October 5, 2020

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KEYWORDS **agroecology, agricultural research, transitions, sustainable development goals, paradigm shift**

## 1 Introduction

Agroecology is now widely advocated as an alternative paradigm to industrial agriculture (Giraldo, 2019; Kremen et al., 2012; Rausser et al., 2019). In discussions about international agricultural research to increase food security and well-being, however, agroecology is contested. *Box 1* defines agroecology as used in this opinion piece. On the one hand, a growing number of farmers, consumer groups and multilateral agencies are committed to agroecology (Bellon and Ollivier, 2018; Frison, 2020; Mier y Terán Giménez Cacho et al., 2018). For agriculture to become more sustainable, as they argue, farmers require greater independence from external inputs, and advance circular agriculture (Harris et al., 2019; HLPE, 2019; IAASTD, 2009). On the other hand, some researchers, governments and private sector actors argue for the intensification of agriculture through different versions of a Green Revolution (Buckwell et al., 2014; Levidow, 2018; World Bank, 2008). Both sides seek means to feed a growing population. Yet, their conclusions about the right technologies, business models or trade policies to achieve this goal differ (Foran et al., 2014). In this position paper, I explore the value of agroecology to support the transformation of agriculture and food systems to deliver food, health and well-being within planetary boundaries (Hatt et al. 2016; Gliessman, 2011).

The perspective offered in this article is informed by my work with one major stakeholder among the many international agricultural research organisations, the CGIAR (Consultative Group on International Agricultural Research). Organised in 15 centres with offices in over 70 countries, the CGIAR is the largest global research partnership dedicated to poverty reduction, food and nutrition security, and environmental health (CGIAR, 2015; ISPC, 2013). Though it is only one such organisation, the CGIAR has far-reaching ripple effects that can be seen in national agricultural research and extension organisations in Africa, Asia and Latin America. Currently, the CGIAR is undergoing a comprehensive organisational change towards 'One' CGIAR[3]. This reform provides an opportunity to bring agroecology principles to the fore in helping to guide the formulation of research questions, innovation and partnerships. Thus far, however, the conversation about how to better integrate agroecology into the CGIAR has been on the individual level rather than institutional.

In this invited paper, I analyse why this conversation about agroecology is not happening at a broader level, using the CGIAR as an entry point to this discussion. I further present five contributions agroecology offers international agricultural research to move towards more sustainable agriculture and improved food systems, especially when being adopted as an

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[3] The reform to transition to 'One' CGIAR aims to accelerate progress in key areas where innovation is needed, and as a result, deliver faster and more effectively on the SDGs by 2030. Essential changes shall lead to a unified governance, institutional integration, new research modalities, country engagement, and funding. For details see www.cgiar.org

Agroecology is an inter- and transdisciplinary science that studies the ecology of agriculture and food system to derive general principles about sustainable production, processing, consumption and disposal of food and non-food products. It generates evidence that helps developing equitable, ecologically sustainable, resilient farm and food systems delivering food and nutrition, fibre, energy and ecosystem services. In recent years, it has become useful to distinguish between agroecology as a science, a social movement that advocates for agroecological transitions of farms and food systems, and an agricultural practice on farms, informed by agroecological principles. Several community-based initiatives (such as the international peasant's movement La Via Campesina) and international organisations defined these agroecological principles. In 2019, the High-Level Panel of Experts at the Committee on World Food Security (CFS), see HLPE, 2019, expanded FAO's ten elements into 13 principles under three major categories:

1. Improve resource efficiency (recycling of nutrients in biomass, reduction of external inputs);
2. Strength and resilience (improving soil health, animal health, biodiversity, enhance synergies and economic diversification),
3. Secure social equity and responsibility (enhance co-creation, social values and diets, improve fairness, enhance connectivity, strength and land use and natural resource governance, ensure participation).

In short: Agroecology is the ecology of sustainable agriculture and food systems (Altieri, 1995).

BOX 1
Defining agroecology

overarching framework. In moving forward, I propose an open dialogue between the CGIAR and agroecology advocates, a multi-actor research platform and active policy engagement to strengthen agroecology principles in national and regional development plans. International agricultural research re-oriented in this way can undoubtedly be at the forefront of improving the sustainability of agriculture and nutrition with due respect for planetary boundaries.

## 2 The problem

Agroecology is not new to the CGIAR. There is an array of excellent research that resonates with agroecology and its principles, including pre-existing studies. Take early soil microbial research of TSBF (Tropical Soil Biology and Fertility Program) that was later merged into CIAT (International Center for Tropical Agriculture), for example, or research to close nutrient flows on smallholder farms (Bekunda and Woomer, 1996). Researchers understood soil health comprehensively and contributed directly to today's agroecology paradigm. Also widely recognised are the cereal-legume inter-cropping systems developed by IITA (International Institute for Tropical Agriculture) in West Africa, biological pest control, and methods for better crop-livestock integration by ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) in southern Africa to improve soil fertility, human nutrition and income (Homann-Kee Tui et al., 2020). Early versions of agroforestry research at World Agroforestry investigated biological processes to improve the functionality of managed ecosystems (Steppler and Nair, 1988). Other examples include research on perennial grains (Rogé et al., 2017), trade-off analysis between the use of crop residue biomass (Tittonell et al., 2015), and recently, barriers to the agroecological transition of countries, such as Nicaragua (Schiller et al., 2020). Research on landscape restoration has been implicitly organised around agroecological principles. Moreover, the CGIAR has gradually expanded its research agenda from crops to natural resource management and policies (Harwood et al., 2006). Today, researchers in several CGIAR Research Programs support a transition to sustainable agriculture with knowledge, tools and capacity development that complies with agroecology (see for example FAO, 2015).

Given the remarkable development outcomes achievable from such research, what then is the source of the controversy that divides the international agricultural research community over the adoption of agroecological principles? One source is programmatic: there is a long-held approach that advocates agricultural intensification as a means to support global food and security. Although overly simplified, this Neo-Malthusian justification (Demont et al., 2007) considers increased farm productivity a central pathway to food and nutrition security. This thinking often leads back to research aimed at improving food crops to result in higher yields, which is one of the founding principles of the first generation of CGIAR centres. This is not to say that crop improvement has lost relevance. Current yield levels of maize, wheat, rice would be impossible without cutting-edge crops research. Researchers have developed food crops resistant to abiotic and biotic stresses, productive livestock breeds and multipurpose trees that provide farmers with additional income. But closing yield gaps through the improvement of farm commodities alone – as many researchers have argued before – is not a sure means by which the world meets nutritional demands of 9 billion people by 2050 (Blesh et al., 2019; Pretty, 1995; Pretty et al., 2003).

Moreover, crop improvement alone will not make food systems more just and ecologically sustainable. There are also issues of distributional barriers (UNDP, 2016), food loss and waste (Sheahan and Barrett, 2017), land health (Stevens, 2015), agrobiodiversity (Bailey, 2016), and the feasibility of policy measures to consider when transforming food systems towards greater sustainability and fairness. Yet, the focus on closing yield gaps often dominates the conversation about agricultural development in low- and middle-income countries. Therefore, IPES-Food (2016) identifies eight pertinent lock-ins that keep agricultural and agricultural research from supporting more fundamental farm and food system transformations.

Secondly, there are arguments about the 'right' agricultural technology. One division between agroecology and the CGIAR is around Genetically Modified Organisms – GMOs (Altieri, 2001). The CGIAR is seen as a stronghold of GMO research, rooted in the Green Revolution (Holt-Giménez and Altieri, 2013). Many in the agroecology movement reject GMOs as a means of improving crops and livestock. Also, up for debate is the difference in opinion about biofortification to combat micronutrient deficiencies in humans rather than system-based nutritional improvements (Tan et al., 2020). In that 'tug of war' between the schools of thought, agroecology and sustainable intensification seem two incompatible concepts (for details see Bernard and Lux, 2017).

Third, international agricultural research is conducted through a series of steps: discovery, proof of concept, piloting and scaling. Discovery research is highly specialised, but the later stages require both technical accuracy and social innovation, and thus are more multidisciplinary and applied in nature. Crop improvement through breeding may successfully increase the adaptability of a plant to a particular environment. But that crop also requires an enabling household economy, human aspiration, seed systems, market institutions and agricultural policies to unlock its genetic potential. Interdisciplinary research that assesses relations between crop physiology, soils, human nutrition and household economy (see for example Barrett and Bevis, 2015) are hardly done. Workplace pressure limits the time for reflection – or what Lamine and Dawson (2018) call 'relational reflexivity'.

Fourth, specialised research without integration leads to fragmentation where holistic views of development challenges are most needed. Such fragmentation hinders rather than supports transitions towards sustainable farm and food systems. Driven by the political economy supporting technology fixes, it also reinforces technical innovation from top-to-bottom, an approach the agroecology and the farmer-first movements reject (see Chambers et al., 1989; Scoones and Thompson, 1994, 2009). As a consequence, adoption rates of agricultural technologies remain low.

Fifth, low levels of technology adoption on the part of farmers has fundamental implications for impact. Compartmentalisation also reduces the ability of research to effectively address socio-ecological fragilities in some parts of the CGIAR mandate regions, especially in the Horn of Africa, West Africa and parts of South-East Asia. Moreover, there is relatively little awareness of the external effects that some agricultural technologies generate. Impact studies motivated by accountability rather than learning focus on crop yields, farm productivity and economic benefits. Less emphasis is put on environmental and social impacts. Although the impact agenda has widened in recent years, it is still too narrow for many advocating for agroecology.

Several of these divisions are resolvable (e.g. agreeing on unified outcome targets, strategies to improve adoption and impact), settling others is more complicated (e.g. defining the 'right' technology). For more information on concerns across these five domains see, for example, Hall et al., 2003 and Leeuwis et al., 2018.

## 3 Contributions

Agroecology offers international agricultural research a framework to improve the effectiveness and efficiency of research. Some aspects of this framework will strengthen the ecological foundations of agriculture; others draw attention to the social and political processes in areas where change is most needed to support sustainability. Five of these contributions stand out.

a) Unifying vision based on joint values

The first significant contribution that agroecology offers to international agricultural research is a means for critical reflection of the social norms and human values that underpin sustainable agriculture and food systems. Contributions include the focus on:

- 'Multifunctionality' of agriculture, food and environmental services, where food-producing landscapes can also serve as a harbour for biodiversity, as well as for cultural heritage – obvious but cannot be taken for granted.
- 'Equity', especially as related to fair trade, climate justice, food sovereignty.
- 'Energy and resource efficiency', especially with regard to fossil fuels, by increasing optimisation of ecological processes and circular resource economies.
- 'Holistic transition concepts' that recognise the linkages between farming practices, value chain actions, consumer behaviour and policies and politics, all linked through actors with explicit but often invisible power dynamics (Bezner Kerr et al., 2019).
- 'Pluralism', recognition of diversity in decision-making within the international agricultural research community, recognising the value of cultural diversity, gender and knowledge. Seeking diversity in technical and social solutions.

b) Unlocking synergies

The second significant contribution of agroecology recognises the complexity of farm and food systems and helps to operationalise it in lab and field research. Agroecology approaches:

- 'Provide a multi-level perspective' that allows seeing the back- and forward linkages between people, technologies and development outcomes on farms and in societies. Also, such a perspective helps to analyse trade-offs and identify synergies supporting agroecological transitions.
- 'Promote defragmentation': the systems-orientation of agroecology weaves components of farm enterprises together, such as 'One Health' concepts do when seeking to improve synergies between the health of soils, plants, animals and humans on farms.
- 'Advocate for geographical diversification' by working on geographically interconnected agriculture challenges in the Global South and the Global North in tandem; research to support global policy coherence is such an example.
- 'Embrace multidisciplinary' by involving both biophysical and social sciences to better understand the complexity

of transitions towards sustainable farming, especially during piloting and scaling.
- 'Improve the Theory of Change' supporting a flexible, learning-oriented approach addressing political and economic power locks-in, especially in view of scaling the impact of technologies and knowledge.

c) Improving priority setting
Thirdly, agroecology helps to identify entry- and leverage points that support farm and food system transitions and help to broaden research and development partnerships between public organisations, the private sector and the sustainable agriculture and food movements. Agroecology helps to:
- 'Identify and address knowledge gaps' across all science domains, ranging from crop biology to food policies, commodity markets, consumers and human behaviour (Bellamy and Ioris, 2017).
- 'Advance the co-design of research and co-creation of knowledge', as promoted by Bergez et al. (2019) or Page et al. (2016), which will ensure that from the very beginning of a research initiative farmers on the ground bring their experience to the research process, improve the design and uptake of technologies, and help research to learn from social movements for scaling science-based technical, economic, social or policy-related solutions.
- 'Increase return on investment', in other words, agroecology would not only make research more applicable but increase the return on investment of funders – mainly development-oriented agencies measuring direct impact on poverty reduction, food and nutrition security and food sovereignty.
- 'Expand sustainability benchmarks' informed by the elements of agroecology (see *Box 1*) to derive better criteria for ex-ante impact assessments and improved prognoses of benefits of development interventions.
- 'Reorganise division of labour' and set criteria for effective partnerships, especially when developing agroecological pilot programs and when making scaling efforts.

d) Tracking impact rigorously
While a unifying vision and joint values 'to do the right thing', this fourth contribution of agroecology is critical for 'doing things right'. Contributions include:
- 'Alignment of impact assessment criteria and indicators' with the multiple functions of agriculture, rigorous impact assessment against SDGs and planetary boundaries.
- 'Expansions of development outcome indicators'. Applying an agroecological perspective to impact assessments will widen assessment domains and indicators beyond the farm into society where production links with processing, trade and consumption.
- 'Integrated metrics framework' to assess the impact of technologies and practices concerning sustainability outcomes.
- 'Assessments of negative externalities', undesirable consequences of agricultural intensification and preventing the external cost of sustainable intensification.
- 'Learn from failed development', assess with rigour technology failures, and assess dis-adoption of technologies (see, for example, Simtowe and Mausch, 2018).

e) Broadening accountability
Finally, through agroecology international agricultural research received inputs towards additional performance management criteria.
- 'Expand the definition of stakeholders', for example, by multilateral, civil society organisations or the global peasant movement and consumer groups, all equipped with leverage and multiplier potential at the national and regional level.
- 'Embrace social business and social entrepreneurship' (for examples see World Bank, 2012), based on new accountability standards contribute to new business models, including versions of fair-trade.
- 'Progress citizen-led collaboration'; although no blueprint for positive outcomes (Gaventa and Barrett, 2010), partnerships with consumer groups and farmer organisations are essential, for example, when developing product profiles for new food crop varieties – their knowledge and needs should figure into CGIAR's priorities for the future. Such citizen-led partnerships also build on excellent farmer-participatory research done with partners from the CGIAR in the past.
- 'Improved performance' through impact evaluation that involves multiple users of technologies, direct, quantitative feedback to strengthen impact pathways (Springer-Heinze et al., 2003).
- 'Improve economic efficiency'; although a good cost-benefit ratio (Raitzer and Kelley, 2008), there is room to improve through better-informed decisions about resource allocation to research projects in line with overarching sustainability targets.

Delivering on the mission of the CGIAR requires integrated thinking during the formulation of development results, the innovation needed to achieve results, along with the research questions, partnerships and management procedures to manage highly complex innovation processes. While only a few would disagree with the overarching areas where the impact is urgently needed, the science of agroecology helps to specify lower-level targets better connected to the agroecology principles. Finally, an agroecology framework enables a more universally shared commitment to international agricultural research delivering development results, and compliance of research with overarching sustainability targets. In other words, by doing the right thing right, the scaling performance of sustainability outcomes increases.

## 4 Institutional innovation

As agroecology gains traction, the 'what next' question shifts in the foreground. It should not come as a surprise that I argue for a bold move to integrate agroecology into international agricultural research more explicitly and visibly. Each of the actors in international agricultural research must find its way in doing so. Among the many strategic moves the international agricultural research community could take, I present three.

First, it is time for the CGIAR and agroecology proponents to change mindsets and beliefs to engage more actively in unbiased, impartial conversations about the utility of agroecology as a framework for ending hunger by 2030 – using science to transform food, land and water systems amidst a climate crisis. Fundamental questions are: What is the purpose of agricultural transformation? What are the preferred models for supporting the transitions? Who should govern agricultural research to support transitions? Although these questions create friction between the different schools of thought (for its multilateral dimensions see Duncan and Claeys, 2018), the international agricultural research organisations – and the CGIAR – must have an open conversation with development partners and funders about agroecology and its paradigmatic fundamentals. Such a conversation will not only encourage a shared understanding of agroecology and offer evidence to support a comprehensive agroecological narrative (for a debate on narratives see Rivera-Ferre, 2018). It also avoids what Taylor (2018) calls a depoliticised debate about technological fixes, and places questions around social norms, institutions and politics more prominently on the research agenda. Also, such conversations can help bring up to date the lower-level targets of the CGIAR results framework, especially regarding the reduction of the carbon footprint of food production, the integration of resource flows on farms and landscapes and between urban and rural areas, support towards circular agriculture, dietary diversity and equity in local and global food economies. Finally, such conversations enable all those criticising the CGIAR to see a good share of strategic public research already aligned with global sustainability targets.

Second, the CGIAR could initiate a multi-actor platform aimed at progressing the science of agroecology, in cooperation with FAO and other key partners. As done at CGIAR platforms (e.g. 'Excellence in Breeding', 'Gender' and 'Big Data'), researchers would work with development partners to support agroecology at the national, regional and global level. One benefit of such a platform would be the mainstreaming of agroecology principles in research and outreach. Such a platform aids in developing a shared research agenda, providing methodological support to research programs implemented by several CGIAR centres and partners, helping to integrate research insights into agricultural advisory services, and assists in steering the international policy discourse to support transitions towards sustainable farm and food systems.

Third, as Nelson (2020) suggests, much tighter linkages between agroecological practices, international agricultural research and multilateral policy processes are needed. These include coordination with the UN Committee on World Food Security (CFS), the International Panel of Experts on Sustainable Food Systems (IPES-Food), and TEEB for Agriculture and Food. Undoubtedly, international agricultural research can underpin policy reforms with evidence.

Yet, it would be wrong to rebrand the CGIAR into an 'agroecology research consortium' (see also Mockshell and Kamanda, 2018). There are also many good reasons for maintaining, and in some areas intensifying compartmentalised disciplinary research with a comparative advantage – be it in the field of genetic improvement of crops and livestock, or experiments to understand the decision-making of farmers. But the future focus of research must be less on isolating problems and more on spearheading innovation through integrating new technologies with social innovation in cooperation with bridging agents and multipliers.

What are the benefits of the three strategic moves for farmers, countries and the international community? Overall, I anticipate greater food sovereignty as being demanded by many social movements and local communities. In my opinion, agroecology principles applied in research provide evidence-based strategies for three major transitions. The first aims to increase the well-being of farmers through agriculture, and to strengthen the resilience of small farms to shocks, especially during protracted crises – including those caused by COVID-19 – and in fragile environments. To many farmers in these environments, sustainable agriculture is a livelihood and a safety net at the same time. The second is to ensure that transitions to commercial, market-oriented agriculture become complies with SDG targets. The third support shifts from resource depleting food production to circular agriculture within planetary boundaries. This concerns the Global South and the Global North equally. All three transitions are critical for moving towards sustainable food systems in countries and regions where the CGIAR conducts research.

## 5 Conclusion

In conclusion, agroecology should provide direction to the One CGIAR reform, but the recommendations put forth would be applicable for many others engaging in international agricultural research. If done well, research informed by agroecology guides quests for transforming agriculture and food systems towards sustainability. Although some may object, in my perspective, the question is not whether international agricultural research should adopt a unified position on agroecology or self-claim its promotion on opportunistic grounds. Instead, the science of agroecology offers evidence to advance the needed farm and food system transitions. With strong regional programs and country offices in Africa, Asia, Latin America, Europe and the USA, the CGIAR is in a strategic position to offer such support. But for realising this potential, a paradigm shift towards agroecology is indispensable. The ongoing CGIAR reform is an unprecedented opportunity for nudging this shift.

## Disclaimer

This viewpoint is my personal and does not necessarily reflect opinions the author's employer, donors and research partners. I declare to have no conflict of interests.

## Acknowledgements

The author thanks Andre van Rooyen, Kai Mausch, Anthony Whitbread, the editor and two anonymous reviewers for their valuable suggestions to improve the arguments articulated in this article.

### REFERENCES

Altieri MA (2001) Genetically engineered crops: Separating the myths from the reality. Bull Sci Techn Soc 21(2):130–146, doi:10.1177%2F027046760102100207

Altieri MA (1995) Agroecology: The science of sustainable agriculture. 2nd Edition. London: Intermediate Technology Publications, 433 p

Bailey A (ed) (2016) Mainstreaming agrobiodiversity in sustainable food systems: Scientific foundations for an agrobiodiversity index – summary [online]. Rome: Bioversity International, 32 p. Retrieved from <https://www.bioversityinternational.org/fileadmin/user_upload/campaigns/CBD/Mainstreaming_Agrobiodiversity_Sustainable_Food_Systems_Summary.pdf> [at 7 Dec 2020]

Barrett CB, Bevis LEM (2015) The self-reinforcing feedback between low soil fertility and chronic poverty. Nat Geosci 8:907–912, doi:10.1038/ngeo2591

Bekunda MA, Woomer PL (1996) Organic resource management in banana-based cropping systems of the Lake Victoria Basin , Uganda. Agric Ecosyst Environ 59(3)171–180, doi:10.1016/0167-8809(96)01057-2

Bellamy AS, Ioris AAR (2017) Addressing the knowledge gaps in agroecology and identifying guiding principles for transforming conventional agri-food systems. Sustainability 9(3):330, doi:10.3390/su9030330

Bellon S, Ollivier G (2018) Institutionalizing agroecology in France: Social circulation changes the meaning of an idea. Sustainability 10(5):1380, doi:10.3390/su10051380

Bergez JE, Audouin E, Therond O (eds) (2019) Agroecological transitions: From theory to practice in local participatory design. Cham: Springer, 335 p, doi:10.1007/978-3-030-01953-2

Bernard B, Lux A (2017) How to feed the world sustainably: an overview of the discourse on agroecology and sustainable intensification. Reg Environ Chang 17:1279–1290, doi:10.1007/s10113-016-1027-y

Bezner Kerr R, Hickey C, Lupafya E, Dakishoni L (2019) Repairing rifts or reproducing inequalities? Agroecology, food sovereignty, and gender justice in Malawi. J Peasant Stud 46(7):1499–1518, doi:10.1080/03066150.2018.1547897

Blesh J, Hoey L, Jones AD, Friedmann H, Perfecto I (2019) Development pathways toward "zero hunger". World Dev 118:1–14, doi:10.1016/j.worlddev.2019.02.004

Buckwell A, Uhre AN, Williams A, Poláková J, Blurn WEH, Schiefer J, Lair GJ, Heissenhuber A, Schieβl P, Krämer C, Haber W (2014) The sustainable intensification of European agriculture. A review sponsored by the RISE Foundation [online]. Brussels: RISE Foundation, 98 p. Retrieved from <https://ieep.eu/uploads/articles/attachments/a39b547e-8abe-49d8-94ec-77f751378e34/111120_BROCH_SUST_INTENS_DEF.pdf?v=63664509854> [at 7 Dec 2020]

CGIAR (2015) CGIAR strategy and results: Framework 2016–2030. Redefining how CGIAR does business until 2030 [online]. Retrieved from <https://www.cgiar.org/how-we-work/strategy/> [at 7 Dec 2020]

Chambers R, Pacey A, Thrupp LA (1989) Farmer first: Farmer innovation and agricultural research. London: Intermediate Technology Publ, 218 p

Demont M, Jouve P, Stessens J, Tollens E (2007) Boserup versus Malthus revisited: Evolution of farming systems in northern Côte d'Ivoire. Agric Syst 93(1–3):215–228, doi:10.1016/j.agsy.2006.05.006

Duncan J, Claeys P (2018) Politicizing food security governance through participation: opportunities and opposition. Food Secur 10:1411–1424, doi:10.1007/s12571-018-0852-x

FAO (2015) Agroecology: A global movement for food security and sovereignty [online]. In: FAO (ed) Agroecology for food security and nutrition. Proceedings of the FAO International Symposium, Rome, Italy, 18–19 Sept 2014, 1–13. Retrieved from <http://www.fao.org/documents/card/en/c/d1f541b5-39b8-4992-b764-/> [at 7 Dec 2020]

Foran T, Butler JRA, Williams LJ, Wanjura WJ, Hall A, Carter L, Carberry PS (2014) Taking complexity in food systems seriously: An interdisciplinary analysis. World Dev 61:85–101, doi:10.1016/j.worlddev.2014.03.023

Frison E (2020) An important step forward for agroecology in Rome. Agroecol Sustain Food Syst 44(4):417–418, doi:10.1080/21683565.2020.1697478

Gaventa J, Barrett G (2010) So what difference does it make? Mapping the outcomes of citizen engagement. IDS Working Papers 347:1–72, i–ii, doi:10.1111/j.2040-0209.2010.00347_1.x

Giraldo OF (2019) Political ecology of agriculture. Cham: Springer, doi:10.1007/978-3-030-11824-2

Gliessman S (2011) Transforming food systems to sustainability with agroecology. J Sustain Agric 35(8):823–825, doi:10.1080/10440046.2011.611585

Hall A, Sulaiman VR, Clark N, Yoganand B (2003) From measuring impact to learning institutional lessons: an innovation systems perspective on improving the management of international agricultural research. Agric Syst 78(2):213–241, doi:10.1016/S0308-521X(03)00127-6

Harris J, Anderson M, Clément C, Nisbett N (eds) (2019) The political economy of food. IDS Bull 50(2), doi:10.19088/1968-2019.112

Harwood RR, Place F, Kassam AH, Gregersen HM (2006) International public goods through integrated natural resources management research in CGIAR partnerships. Exp Agric 42(2), 375–397, doi:10.1017/S0014479706003802

Hatt S, Artu S, Brédart D, Lassois L, Francis F, Haubruge É, Garré S, Stassart PM, Dufrêne M, Monty A, Boeraeve F (2016) Towards sustainable food systems: The concept of agroecology and how it questions current research practices. A review. Biotechnol Agron Soc Environ 20(S1), 215–224, doi:10.25518/1780-4507.12997

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]

Holt-Giménez E, Altieri MA (2013) Agroecology, food sovereignty, and the new green revolution. Agroecol Sustain Food Syst 37(1):90–102, doi:10.1080/10440046.2012.716388

Homann-Kee Tui S, Valdivia RO, Descheemaeker K, Senda T, Masikati P, Makumbe MT, van Rooyen AF (2020) Crop-livestock integration to enhance ecosystem services in sustainable food systems. In: Rusinamhodzi L (ed) The role of ecosystem services in sustainable food systems. London: Elsevier/Academic Press, doi:10.1016/b978-0-12-816436-5.00008-1

IAASTD (2009) Global report: International Assessment of Agricultural knowledge, science and technology for development. Washington: Island Press, 592 p, Agriculture at a crossroads. Retrieved from <https://www.weltagrarbericht.de/fileadmin/files/weltagrarbericht/IAASTDBerichte/GlobalReport.pdf>

IPES-Food (2016) From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems [online]. Retrieved from <http://www.ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf> [at 7 Dec 2020]

ISPC (2013) CGIAR System-Level Outcomes (SLOs), their impact pathways and inter-linkages [online]. ISPC White paper. Retrieved from <https://cas.cgiar.org/sites/default/files/ISPC_WhitePaper_SLOsIPs.pdf>

Kremen C, Iles A, Bacon C (2012) Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecol Soc 17(4):44, doi:10.5751/ES-05103-170444

Lamine C, Dawson J (2018) The agroecology of food systems: Reconnecting agriculture, food, and the environment. Agroecol Sustain Food Syst 42(6):629–636, doi:10.1080/21683565.2018.1432517

Leeuwis C, Klerkx L, Schut M (2018) Reforming the research policy and impact culture in the CGIAR: Integrating science and systemic capacity development. Glob Food Sec 16:17–21, doi:10.1016/j.gfs.2017.06.002

Levidow L (2018) Sustainable intensification: Agroecological appropriation or contestation? In: Constance DH, Konefal JT, Hatanaka M (eds) Contested sustainability discourses in the agrifood system, London: Routhledge, 19–41, doi:10.4324/9781315161297

Mier y Terán Giménez Cacho M, Giraldo OF, Aldasoro M, Morales H, Ferguson BG, Rosset P, Khadse A, Campos C (2018) Bringing agroecology to scale: key drivers and emblematic cases. Agroecol Sustain Food 42(6): 637–665, doi:10.1080/21683565.2018.1443313

Mockshell J, Kamanda J (2018) Beyond the agroecological and sustainable agricultural intensification debate: Is blended sustainability the way forward? Int J Agric Sustain 16(2)127–149, doi:10.1080/14735903.2018.1448047

Nelson R (2020) Viewpoint: International agriculture's needed shift from energy intensification to agroecological intensification. Food Policy 91: 101815, doi:10.1016/j.foodpol.2019.101815

Page GG, Wise RM, Lindenfeld L, Moug P, Hodgson A, Wyborn C, Fazey I (2016) Co-designing transformation research: lessons learned from research on deliberate practices for transformation. Curr Opin Environ Sustain 20:86–92, doi:10.1016/j.cosust.2016.09.001

Pretty JN (1995) Regenerating agriculture: Policies and practice for sustainability and self-reliance. Washington: Joseph Henry Press, 336 p, doi:10.17226/4930

Pretty JN, Morison JIL, Hine RE (2003) Reducing food poverty by increasing agricultural sustainability in developing countries. Agric Ecosyst Environ 95(1):217–234, doi:10.1016/S0167-8809(02)00087-7

Raitzer DA, Kelley TG (2008) Benefit–cost meta-analysis of investment in the International Agricultural Research Centers of the CGIAR. Agric Syst 96(1–3):108–123, doi:10.1016/j.agsy.2007.06.004

Rausser G, Sexton S, Zilberman D (2019) The economics of the naturalist food paradigm. Annu Rev Resour Economics 11:217–236, doi:10.1146/annurev-resource-100516-053623

Rivera-Ferre MG (2018) The resignification process of agroecology: Competing narratives from governments, civil society and intergovernmental organisations. Agroecol Sustain Food Syst 42(6):666–685, doi:10.1080/21683565.2018.1437498

Rogé P, Diarisso T, Diallo F, Boiré Y, Goïta D, Peter B, Macalou M, Weltzien E, Snapp S (2017) Perennial grain crops in the West Soudanian savanna of Mali: perspectives from agroecology and gendered spaces. Int J Agric Sustain 15(5):555–574, doi:10.1080/14735903.2017.1372850

Schiller KJF, Klerkx L, Poortvliet PM, Godek W (2020) Exploring barriers to the agroecological transition in Nicaragua: A technological innovation systems approach. Agroecol Sustain Food Syst 44(1):88–132, doi:10.1080/21683565.2019.1602097

Scoones I, Thompson J (eds) (1994) Beyond farmer first: Rural people's knowledge, agricultural research andextension practice. Rugby: Practical Action Publishing, 320 p, doi:10.3362/9781780442372

Scoones I, Thompson J (eds) (2009) Farmer first revisited: Innovation for agricultural research and development. Rugby: Practical Action Publishing, 386 p

Sheahan M, Barrett CB (2017) Review: Food loss and waste in Sub-Saharan Africa. Food Policy 70:1–12, doi:10.1016/j.foodpol.2017.03.012

Simtowe F, Mausch K (2018) Who is quitting? An analysis of the dis-adoption of climate smart sorghum varieties in Tanzania. Int J Clim Chang Str 11(3):341–357, doi:10.1108/IJCCSM-01-2018-0007

Springer-Heinze A, Hartwich F, Henderson JS, Horton D, Minde I (2003) Impact pathway analysis: an approach to strengthening the impact orientation of agricultural research. Agric Syst 78(2):267–285, doi:10.1016/S0308-521X(03)00129-X

Steppler HA, Nair PKR (eds) (1988) Agroforestry – A decade of development. Nairobi: International Council for Research in Agroforestry, 335 p

Stevens A (2015) The economics of soil health: Current knowledge, open questions, and policy implications [online]. Retrieved from <http://food.berkeley.edu/wp-content/uploads/2017/08/BFI_Soil_Health_Report_June19.pdf> [at 7 Dec 2020]

Tan W, Thompson S, Ahn K (2020) The political economy of food. Book review. Agroecol Sustain Food Syst 44(2):279–281, doi:10.1080/21683565.2019.1680477

Taylor M (2018) Climate-smart agriculture: what is it good for? J Peasant Stud 45(1):89–107, doi:10.1080/03066150.2017.1312355

Tittonell P, Gérard B, Erenstein O (2015) Trade-offs around crop residue biomass in smallholder crop-livestock systems – What's next? Agric Syst 134:119–128, doi:10.1016/j.agsy.2015.02.003

UNDP (2016) Human Development Report 2016: Human Development for Everyone [online]. New York: United Nations Development Programme. Retrieved from <http://hdr.undp.org/sites/default/files/HDR2016_EN_Overview_Web.pdf> [at 7 Dec 2020]

World Bank (2008) World Development Report 2008: Agriculture for development. Washington, DC: World Bank, http://hdl.handle.net/10986/5990

World Bank (2012) Agricultural Innovation Systems. An investment sourcebook. Washington, DC: World Bank, doi:10.1596/978-0-8213-8684-2

RESEARCH ARTICLE

# Co-inoculation with rhizobia and mycorrhizal fungi increases yield and crude protein content of cowpea (*Vigna unguiculata* (L.) Walp.) under drought stress

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Received: January 13, 2020
Revised: April 16, 2020
Accepted: June 11, 2020

HIGHLIGHTS

- **Cowpea is one of the most consumed legumes worldwide due to its high seed protein content.**
- **Rhizobial bacteria and arbuscular mycorrhizal fungi can improve growth and yield of leguminous plants.**
- **The selection of appropriate microorganisms is essential to the success of symbiosis.**
- **Co-inoculation with selected beneficial microorganisms increased crude protein content in the grain of plants under drought stress.**
- **This eco-friendly strategy can be a useful tool in more sustainable agriculture to mitigate climate changes.**

KEYWORDS **AMF, drought, rhizobia, tripartite symbiosis, *Vigna unguiculata* (L.) Walp.**

## Abstract

Recent trends in sustainable agricultural production seek improved bioinoculants that can improve crop adaptation and production and reduce external inputs of pesticides and synthetic fertilisers, particularly under abiotic and biotic stress conditions. Drought is one of the critical and more frequent conditions that can drastically reduce plant biomass and yield. In this sense, the use of bioinoculants is a biological strategy to mitigate climate change and reduce the water needs of plants. Leguminous plants are very important in improving sustainable cropping systems because they can form effective symbiotic associations with both nitrogen-fixing bacteria and arbuscular mycorrhizal fungi. These microorganisms can act as an alternative source of nitrogen and can increase phosphorus utilisation from soils and fertilisers. Cowpea is a multipurpose crop that has caused a great interest due to its resistance to abiotic stress. This pot experiment in a greenhouse with non-sterilised soil aimed to test the effect of three previously selected rhizobial bacteria (*Rhizobium* sp. (B1), *Bradyrhizobium elkanii* (B2) and *Bradyrhizobium* sp. (B3)) and arbuscular mycorrhizal fungi (*Claroideoglomus claroideum* BEG210) on the yield and crude protein content of cowpea under drought conditions and also to compare the competitiveness of the inoculated bacteria with native rhizobial bacteria naturally present in the soil. The combined inoculation with each bacteria and arbuscular mycorrhizal fungi *Claroideoglomus claroideum* BEG210 was shown to increase the crude protein content of cowpea seeds in plants under drought stress (25 % of field capacity) by 13 %, 17 %, and 30 %, respectively. This study shows that these microorganisms are potentially resistant to drought and can be used as a biotechnological tool for sustainable agriculture under drought conditions.

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## 1 Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is an annual legume crop native of Africa and is the most widely cultivated seed-legume in arid and semi-arid areas (Alkama et al., 2009; Johnson et al., 2013; Lazaridi et al., 2017). It is adapted to high temperatures (20 to 35 °C) and can grow well in a wide range of soil textures and with only 188 mm of annual rainfall. Its growth period can range between 90 to 240 days, depending on the climatic conditions and the maturity period of the cultivar (Ngalamu et al., 2014; Carvalho et al., 2017).

It has been estimated that the total cultivated area has increased in the last years from approximately 2.4 million hectares in 1961 to around 12.5 million hectares in 2017 (FAOSTAT, 2017). Despite the wide distribution of cowpea, around 98 % of the world production is located in Africa (12.3 million hectares ) (Alkama et al., 2009; Oliveira et al., 2017).

Cowpea seeds provide a rich source of proteins (23 %), carbohydrates (56 %), fibre (4 %) and calories, as well as minerals and vitamins, and for this reason are sometimes called "poor man's meat" (Iqbal et al., 2006). Additionally, cowpea can also provide an alternative protein source for people that suffer from allergies to soybean protein (Ravelombola et al., 2016).

Nowadays, the increasing food demand, the rising global temperatures, and global water scarcity have led to a need to produce more food with less water (Oliveira et al., 2017). Water scarcity is one of the main reasons for the reduction in agricultural productivity because it can lead to anatomical, morphological, physiological, and biochemical modifications that affect plant growth and development (Bezerra et al., 2003). In fact, according to Bastos et al. (2011), well-watered cowpea plants can produce more than 1,000 kg grain ha$^{-1}$, but water scarcity can reduce this potential to approximately 360 kg ha$^{-1}$. In this sense, the understanding of the physiological, biochemical, and agromorphological mechanisms that can explain the resistance of cowpea varieties to drought is of extreme importance (Cruz de Carvalho, 2000). The physiological mechanisms include the closing of the stomata when the water in the soil is not sufficient and the decrease in the transpiration and photosynthetic rates. The biochemical mechanisms involve the osmotic adjustment which is characterised by the accumulation of organic solutes to maintain the cell turgor, and the agromorphological processes include the turning of the leaves upwards to protect them from excessive temperatures and the reduction in the root volume (Krouma, 2010; Hall, 2012; Halilou et al., 2015). Despite the inherent resistance of cowpea plants to the drought, the inoculation of cowpea and other legumes with beneficial and drought-resistant microorganisms, such as rhizobial bacteria and arbuscular mycorrhizal fungi (AMF), also has a great potential to reduce the negative effects of water scarcity and global warming on cowpea plants. A heterogeneous group of slow-growing rhizobial bacteria belonging to the genus *Bradyrhizobium* and known as "cowpea-miscellany" has the ability to nodulate cowpea roots (Allen and Allen, 1981; Appunu et al., 2009), increasing plant resistance to high temperatures and water deficit and reducing the need for chemical fertiliser inputs. *Bradyrhizobium elkanii*, *B. yuanmingense*, and *B. japonicum* are among the main rhizobial species associated with cowpea (Zhang et al., 2008).

The association with AMF is a non-specific, highly compatible, and long-lasting mutualism, whereby both partners have advantages (Abdel-Fattah et al., 2011; Harrison, 1998). AMF can be applied to increase the growth potential and reduce water and fertiliser inputs. Indeed, in this symbiosis, the fungal hyphae (thread-like structures) spread through the soil, taking up nutrients such as phosphorus and absorbing water and transporting them to the plant root, while receiving sugars from the plant in return. This association between AMF and plants can increase drought tolerance (Augé et al., 2001; Oliveira et al., 2017) and consequently improve cowpea yield under adverse environmental conditions.

Co-inoculation with both rhizobia and AMF in legumes results in a mutualistic tripartite symbiosis (Antunes and Goss, 2005) that usually leads to a higher increase of growth and yield than that resulting from single inoculation with one microorganism (Chalk et al., 2006; Marulanda et al., 2006). In fact, in this kind of symbiosis, the presence of one microorganism can affect the activity of the other and, consequently, the interaction of both has normally a positive effect on the host plant (Vejsadova et al., 1993; Xie et al., 1995).

The objective of the present work was to evaluate the effect of single and co-inoculation with several rhizobial bacteria (*Rhizobium* sp., *Bradyrhizobium elkanii* and *Bradyrhizobium* sp.) and AMF (*Claroideoglomus claroideum* BEG210) on the growth, yield, and crude protein content of cowpea seeds under drought conditions and compare the competitiveness of the inoculated bacteria with those naturally present in the soil.

## 2 Materials and methods

### 2.1 Bacterial inoculant and arbuscular mycorrhizal fungi inoculant

The bacterial strains used in this work were isolated from fresh surface sterilised root nodules of cowpea plants and previously selected among others according to their performance in in vitro experiments. Bacteria B1 and B2 were collected in Elvas, Portugal (39'23'59.72''N, 7'53'25.99''W), in July 2014, and bacteria B3 were collected in Vila Real, Portugal (41'28.54''N, 7'74.14''W), in September 2014. The bacteria identification was performed by amplification of 16S rDNA using the universal primers fD1 and rD1 (Weisburg et al., 1991). Furthermore, for multilocus sequence analysis (MLSA) and in order to identify the isolates at the species level, this analysis was complemented with six housekeeping genes: *recA* (DNA recombination protein), *gyrB* (DNA gyrase B), *SMc00019* (conserved hypothetical protein), *thrA* (homoserine dehydrogenase), *atpD* (atpD synthase β-subunit), and *truA* (RNA pseudouridine synthase A) (Haukka et al., 1998; Gaunt et al., 2001; Zhang et al., 2012). Taxonomic position at the symbiovar level was determined by the inferred phylogenies based on the symbiotic genes of nodulation: *nodA* (N-acyltransferase nodulation protein A) and *nodC* (N-acetylglucosaminyltransferase) (*Table 1*). PCR mixtures were performed with 7.5 µl of

TABLE 1
List of primers used in this work for the molecular identification of collected rhizobial bacteria

| Primers | Sequence (5'–3') | Reference |
|---|---|---|
| fD1 | AGA GTT TGA TCC TGG CTC AG | Weisburg et al., 1991 |
| rD1 | AAG GAG GTG ATC CAG CC | |
| thrAB-F | TGC TTC GTC GAR YTG ATG G | Zhang et al., 2012 |
| thrAB-R | ACR CCC ATC ACC TGY GCR ATC | |
| thrAMRS-F | TAA TAC GAC TCA CTA TAG GGG CNG GBG GYA TYC CSG TBA TCA AG | modified by Tampakaki from Zhang et al., 2012 |
| thrAMRS-R | GAT TTA GGT GAC ACT ATA GCG YTC GAT NCG RAT SAC YTG SGG | |
| SMc00019B-F | CAT TCV KCS GAR GGV GCS ATG GGY ATC | Zhang et al., 2012 |
| SMc00019B-R | GCG TGB CCB GCS KCG TTS GAV AGC AT | |
| SMc00019MRS-F | TAA TAC GAC TCA CTA TAG GGC ADT TCC TBA THG CCA TGC C | modified by Tampakaki from Zhang et al., 2012 |
| SMc00019MRS-R | GCV GGR CAN KTS AGC CAD CCR TT | Zhang et al., 2012 |
| truAB-F | TAA TAC GAC TCA CTA TAG GGC GCT ACA AGC TCA YYA TCG A | modified by Tampakaki from Zhang et al., 2012 |
| truAB-R | CCS ACC ATS GAG CGB ACC TG | Zhang et al., 2012 |
| truAR-F | TGA CCG TSG AAT ATG ACG G | |
| truAR-R | ACA TCS AGY CGG TCV AGS GT | |
| truAMS-F | TAA TAC GAC TCA CTA TAG GGC AGG TSG CDC ATS TCG AYC T | modified by Tampakaki from Zhang et al., 2012 |
| truAMS-R | GAD CGB AYC TGG TTR TGM AG | Zhang et al., 2012 |
| gyrB340F-T7 | TAA TAC GAC TCA CTA TAG GGT TCG ACC ARA AYT CYT ACA AGG | modified by Tampakaki from Zhang et al., 2012 |
| gyrB1057R-SP6 | GAT TTA GGT GAC ACT ATA GCC AAY TTR TCC TTG GTC TGC G | |
| gyrB-F | ACC GGT CTG CAY CAC CTC GT | Spilker et al., 2009 |
| gyrB-R | YTC GTT GWA RCT GTC GTT CCA CTG C | |
| recA6F | CGK CTS GTA GAG GAY AAA TCG GTG GA | Gaunt et al., 2001 |
| recA555R | CGR ATC TGG TTG ATG AAG ATC ACC AT | |
| atpD273F | SCT GGG SCG YAT CMT GAA CGT | Gaunt et al., 2001 |
| atpD-294F | TAA TAC GAC TCA CTA TAG GGA TCG GCG AGC CGG TCG ACG A | modified from Gaunt et al., 2001 |
| atpD771R | GCC GAC ACT TCC GAA CCN GCC TG | Gaunt et al., 2001 |
| nodA-1 | TGC RGT GGA ARN TRN NCT GGG AAA | Haukka et al., 1998 |
| nodA-2 | GGN CCG TCR TCR AAW GTC ARG TA | |
| nodCF | AYG THG TYG AYG ACG GTT C | Laguerre et al., 2001 |
| nodCFu | AYG THG TYG AYG ACG GIT C | |
| nodCI | CGY GAC AGC CAN TCK CTA TTG | |

master mix (MyTaq HS Mix, 2x of Bioline), 1 µl of each forward and reverse primer, and 5.5 µl of DNA template, with the final volume of 15 µl. Amplified samples were sequenced in Stabvida, Portugal. Nucleotide sequences were corrected using BioEdit software, and homology searches were performed on the National Center for Biotechnology Information (NCBI) server using Basic Local Alignment Search Tool (BLAST) (Altschul et al., 1990).

Bacteria B1, B2, and B3 were identified as *Rhizobium* sp., *Bradyrhizobium elkanii*, and *Bradyrhizobium* sp., respectively, and the obtained sequences for 16S ribosomal RNA region were deposited in Genbank database with the accession numbers MH938299-MH938301.

For the inoculum preparation, each type of bacteria was grown on six plates of Yeast Mannitol Agar media (1 g $L^{-1}$ of yeast extract, 10 g $L^{-1}$ of mannitol, 0.5 g $L^{-1}$ $K_2HPO_4$,0.2 g $L^{-1}$ $MgSO_4{\cdot}7H_2O$, 0.1 g $L^{-1}$ NaCl, and 15 g $L^{-1}$ agar) supplemented with 0.1 g $L^{-1}$ bromothymol blue. After 3 to 5 days of growing, bacterial inoculant was suspended in sterilised 0.8 % NaCl and then transferred to a sterilised mix of peat and vermiculite (1:1).

The AMF isolate *Claroideoglomus claroideum* BEG210 was grown for eight months in a multi-spore pot culture containing a 1:1 (v/v) mixture of zeolite and expanded clay with *Zea mays* L. as the host plant.

## 2.2 Plant culture and experimental design

Cowpea seeds were surface-sterilised with 0.5 % (v/v) sodium hypochlorite (NaClO) for 20 minutes, followed by serial washes with sterilised distilled water. Seeds from cultivar *Fradel*, the only cowpea cultivar registered at the Portuguese National Catalog for commercial use (CNV, 2019), were used. After germination, three seedlings of similar size were kept in each plastic pot (6 litres), containing a mixture of soil, vermiculite, sand and, peat (1:1:1:1, w/w). Non-sterilised soil was used in this work. Chemical analyses of soil mixture revealed the following values: 8.10 % organic matter, pH (1:2.5 w/v water) 5.0, 51 mg $kg^{-1}$ P, and 132 mg $kg^{-1}$ P (method of Égner-Riehm). Each pot was inoculated with approximately 1 g of mix with the selected bacteria or AMF inoculant, according to the different treatments. All pots from the non-bacterial treatments received the same amount of autoclaved peat and vermiculite and sterilised 0.8 % NaCl, and every pot from non-mycorrhizal treatments received the same amount of AMF inoculum autoclaved twice (121 °C, for 30 minutes) on two consecutive days.

The study was conducted in a greenhouse at the University of Trás-os-Montes e Alto Douro, Vila Real, Portugal, during the growing season of cowpea (May to September 2015) under natural conditions of light, temperature, and humidity. Pots were occasionally rotated to different places to minimise the effect of the location in the greenhouse.

For each treatment, twelve pots were prepared and distributed equally for the two water regimes used in the experiment (25 % and 75 % of field water capacity (FC)), in a total of six pots (biological replicates) per treatment and water regime. The FC of the soil in the pots was determined according to Grewal et al. (1990). The water regime of 25 % FC was used to simulate the drought stress, and 75 % FC was used to simulate well-watered plants. After inoculation and during four weeks, all pots were kept at 75 % FC by weighting and watering the pots every two days. The drought stress was initiated four weeks after plant emergence, and it lasted two months until the flowering stage. During this period, the plants were weighed and watered accordingly in order to ensure the amount of required water.

### 2.3 Nodule number and biomass and assessment of AMF colonisation

After a growth period of three months, plants were harvested at full maturation stage, and the number and weight of root nodules were determined.

After counting and weighing the nodules, root systems were used for the estimation of the extent of root colonisation by AMF. For this purpose, roots were cleared in potassium hydroxide (KOH) 2.5 %, at 80 °C for 40 minutes, followed by rinsing with water. Roots were immersed in a staining solution containing 5 % blue ink in vinegar and kept at 80 °C for 5 minutes (Vierheilig et al., 1998). After washing away the staining solution, roots were de-stained with tap water containing some drops of vinegar and examined under a compound microscope for quantitative colonisation assessment by the magnified-intersection method according to McGonigle et al. (1990).

### 2.4 Biomass production, seed yield, and crude protein determination

At harvest, shoots and roots were separated for the evaluation of dry weight. The number of seeds and the weight of 100 seeds were also determined.

Dry samples were analysed for ash (942.05) and for total N (954.01) as Kjeldahl N following the methods of the Association of Official Analytical Chemists (AOAC). Total nitrogen was converted to crude protein using the formula N x 6.25.

### 2.5 Statistical analysis

Statistical analysis was performed using Software SPSS V.25 (SPSS-IBM, Orchard Road-Armonk, New York, NY). Statistical differences were evaluated by one-way and two-way analysis of variance (ANOVA), followed by the post-hoc Duncan's multiple range test ($P<0.05$), to establish treatments and water regime effects. One-way ANOVA was also performed to establish treatment effect within each water regime.

## 3 Results

### 3.1 Cowpea growth

Taking into account the single application of beneficial microorganisms, a significant increase was observed in the shoot weight (*Figure 1A*) of plants under drought stress (25 % of FC) and inoculated with *B. elkanii* (B2), *Bradyrhizobium* sp. (B3), and AMF comparing to the control (1.77, 1.96, and 2.06-fold increase, respectively). Under this water regime, plants single-inoculated with the bacteria B2 and B3 also presented significantly higher shoot weight than plants co-inoculated with the respective bacteria and fungi (B2+AMF and B3+AMF).

No effect was observed in the shoot weight after co-inoculation with rhizobial bacteria and AMF. On the other hand, comparisons between water regimes showed that, with the exception of a single inoculation with B2 that presented similar shoot weight in both water regimes, all of the other treatments resulted in higher shoot weight in well-watered plants (75 % of FC) than in plants under drought stress (25 % of FC). In fact, shoot weight was affected by the water regime ($P<0.001$) and the interaction between the treatment and the water regime ($P<0.001$).

Similarly, root weight was also affected by the water regime ($P<0.001$) and the interaction between the treatment and the water regime ($P<0.05$). Root weight (*Figure 1B*) of well-watered plants (75 % of FC) was not affected by microbial inoculation (either with single or in combination). However, under drought stress (25 % of FC), simple inoculation with fungi led to a 1.69-fold increase in root weight when compared with control cowpea plants. In general, this parameter was higher in well-watered plants (75 % of FC) than in plants under drought stress (25 % of FC), with the exception of plants inoculated with AMF, which presented similar root weight in both water regimes.

### 3.2 Cowpea seed yield

The number of seeds was affected by the water regime ($P<0.001$) and the interaction between the treatment and the water regime ($P<0.05$). The number of seeds (*Figure 2A*) of well-watered plants (75 % of FC) was positively affected by a single inoculation with AMF in comparison to the control group, with 1.53-fold increase. There was no effect of co-inoculations in both water regimes. In general, this parameter was higher in well-watered plants (75 % of FC) than in plants under drought stress (25 % of FC), with the exception of plants co-inoculated with B2 and AMF. The weight of 100 seeds was affected by the treatment ($P<0.001$) and the water regime ($P<0.05$). Although no significant differences were

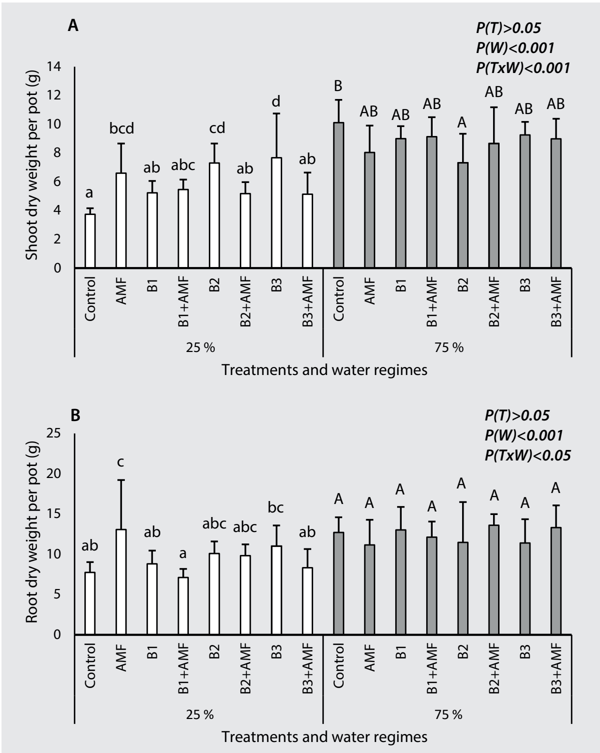


FIGURE 1

Shoot dry weight (A) and root dry weight (B) of cowpea plants uninoculated (control) and inoculated with three rhizobial bacteria (*Rhizobium* sp. (B1), *Bradyrhizobium elkanii* (B2), and *Bradyrhizobium* sp. (B3)), a mixture of arbuscular mycorrhizal fungi (AMF), and co-inoculated with each bacteria and AMF (B1+AMF, B2+AMF, and B3+AMF) subjected to two different water regimes (25 and 75 % of field water capacity). Capped lines indicate standard deviations. Different lowercase letters indicate significant differences (P<0.05) among treatments of plants under drought stress (25% of field capacity), and uppercase letters indicate significant differences (P<0.05) among treatments of well-watered plants (75 % of field capacity), according to Duncan's test.

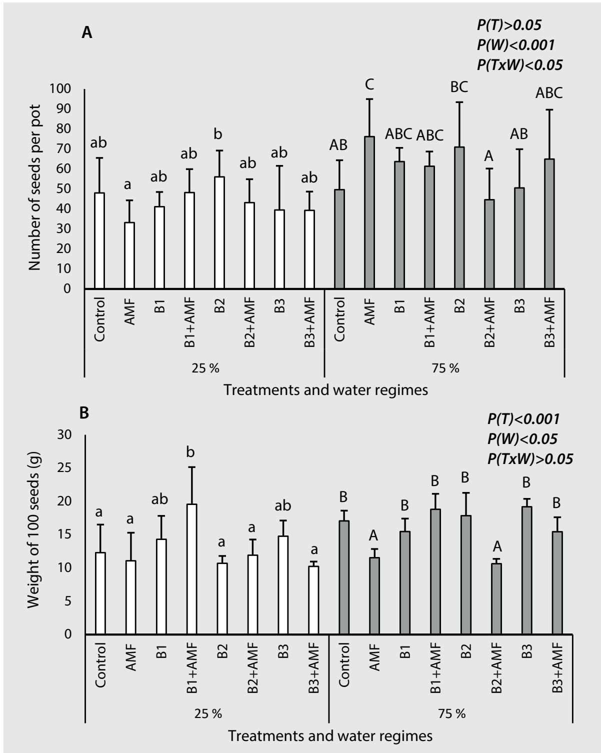


FIGURE 2

The number of seeds (A) and the weight of 100 seeds (B) of cowpea plants uninoculated (control) and inoculated with three rhizobial bacteria (*Rhizobium* sp. (B1), *Bradyrhizobium elkanii* (B2), and *Bradyrhizobium* sp. (B3)), a mixture of arbuscular mycorrhizal fungi (AMF), and co-inoculated with each bacteria and AMF (B1+AMF, B2+AMF, and B3+AMF) subjected to two different water regimes (25 and 75 % of field water capacity). Capped lines indicate standard deviations. Different lowercase letters indicate significant differences (P<0.05) among treatments of plants under drought stress (25 % of field capacity), and uppercase letters indicate significant differences (P<0.05) among treatments of well-watered plants (75 % of field capacity), according to Duncan's test.

observed by single inoculations in the weight of 100 seeds (*Figure 2B*), the co-inoculation of plants under drought stress (25 % of FC) with B1 and AMF presented significantly heavier seeds than control (1.59-fold increase). In well-watered plants (75 % of FC), single inoculation with fungi and co-inoculation with B2 and fungi significantly decreased the weight of seeds comparing with all the other treatments. In general, seeds were slightly heavier in well-watered plants (75 % of FC) than in plants under drought (25 % of FC).

### 3.3 Cowpea seed crude protein

Crude protein content was affected by the treatment (P<0.001), the water regime (P<0.001), and the interaction between the treatment and the water regime (P<0.001).

All plants under drought stress (25 % of FC) and co-inoculated with one bacteria and fungi presented significantly higher (P<0.05) crude protein content in the seeds (*Figure 3*), with a 1.2, 1.3 and, 1.3-fold increase following the co-inoculation with B1 and AMF, B2 and AMF, and B3 and AMF, respectively, when compared to the control. A positive effect was observed by the addition of AMF to B2 and B3 since plants co-inoculated with one of these bacteria and fungi presented significantly higher crude protein in the seeds than plants single-inoculated with either each bacteria or with each fungi. In well-watered plants (75 % of FC), crude protein content in the seeds was significantly higher in plants single-inoculated with fungi and with B2 than in plants co-inoculated with both microorganisms together, with a 1.29-fold increase for each. Comparing single inoculation with all the bacteria, B1 and B2 presented significantly higher crude protein in the seeds than single inoculation with B3 (1.22-fold increase for each).

Taking in account the crude protein yield per pot (*Figure 4*), calculated by taking into account the number of seeds and their weight and the crude protein percentage per treatment

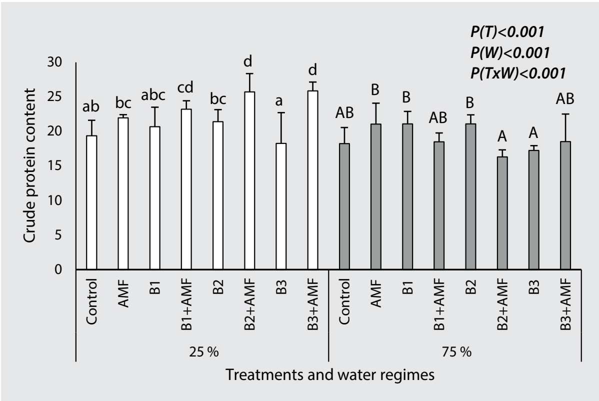


FIGURE 3
Crude protein content in the grains of cowpea plants uninoculated (ontrol) and inoculated with three rhizobial bacteria (*Rhizobium* sp. (B1), *Bradyrhizobium elkanii* (B2), and *Bradyrhizobium* sp. (B3)), a mixture of arbuscular mycorrhizal fungi (AMF), and co-inoculated with each bacteria and AMF (B1+AMF, B2+AMF, and B3+AMF) subjected to two different water regimes (25 and 75 % of field water capacity). Capped lines indicate standard deviations. Different lowercase letters indicate significant differences (P<0.05) among treatments of plants under drought stress (25 % of field capacity), and uppercase letters indicate significant differences (P<0.05) among treatments of well-watered plants (75 % of field capacity), according to Duncan's test.

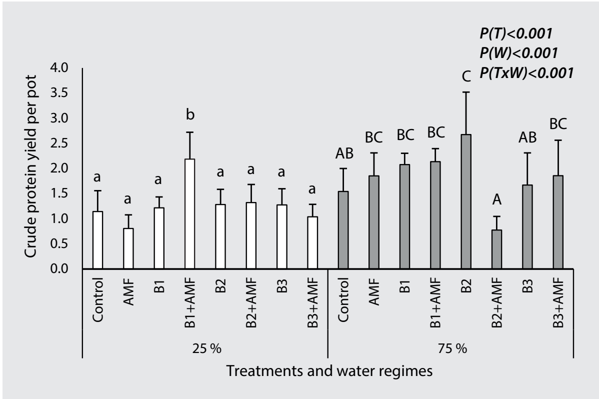


FIGURE 4
Crude protein yield per pot of cowpea plants uninoculated (control) and inoculated with three rhizobial bacteria (*Rhizobium* sp. 32–B1, *Bradyrhizobium elkanii* 57–B2 and *Bradyrhizobium* sp. 63–B3), a mixture of arbuscular mycorrhizal fungi (AMF) and co-inoculated with each bacteria and AMF (B1+AMF, B2+AMF and B3+AMF) subjected to two different water regimes (25 and 75 % of field water capacity). Capped lines are standard deviations. Different lowercase letters indicate significant differences (P<0.05) among treatments, within plants under drought stress (25 % of field capacity) and uppercase letters indicate significant differences (P<0.05) among treatments, within well-watered plants (75 % of field capacity), according to Duncan´s test.

under water stress, only plants co-inoculated with B1 and AMF showed significantly higher crude protein yield than the control plants. On the other hand, the well-watered plants inoculated with B2 showed a significantly higher crude protein yield than control plants, plants co-inoculated with the same bacteria and AMF, and plants single-inoculated with the bacteria B3. Similarly, to crude protein content in the grain, crude protein yield per pot was also affected by the treatment (P<0.001), the water regime (P<0.001), and the interaction between the treatment and the water regime (P<0.001).

## 3.4 Microbial performance

The number of nodules was only affected by the treatment (P<0.05). Although a higher number of nodules (*Figure 5A*) was observed in all inoculated plants under drought stress (25 % of FC), a significant increase was only observed in plants inoculated with B3 when compared to control plants. On the other hand, in well-watered plants (75 % of FC), the number of nodules was positively affected by single inoculation with B2 and B3 and co-inoculation with B1 or B3 and fungi in comparison to the control and plants inoculated only with fungi. A positive correlation was observed between the number and weight of nodules (r=0.444).

The weight of nodules was affected by the treatment (P<0.05), the water regime (P<0.001), and the interaction between both (P<0.05). Well-watered plants (75 % of FC) single- and co-inoculated with each bacteria and AMF presented significantly heavier nodules (*Figure 5B*) than control and plants single inoculated with AMF. Despite the similar number of nodules observed in both water regimes, they were heavier in well-watered plants (75 % owf FC) in all the performed treatments.

Under drought stress (25 % of FC), mycorrhizal colonisation rate (*Figure 5C*) was positively affected by single inoculation with fungi and co-inoculation with *Bradyrhizobium* sp. B3 and AMF, with a 1,41 and 1,44-fold increase compared to control, respectively. Although no significant differences were observed, co-inoculation with bacteria *Rhizobium* sp. B1 or B. elkanii B2 and AMF also increased the mycorrhizal colonisation of plants under drought stress (25 % of FC). In well-watered plants (75 % of FC), co-inoculation with *B. elkanii* B2 and AMF was the unique treatment that increased significantly mycorrhizal colonisation rate comparing with control, with a 1.47-fold increase. Mycorrhization rate followed the same profile within each water regime. Indeed, this parameter was only affected by the treatment (P<0.05).

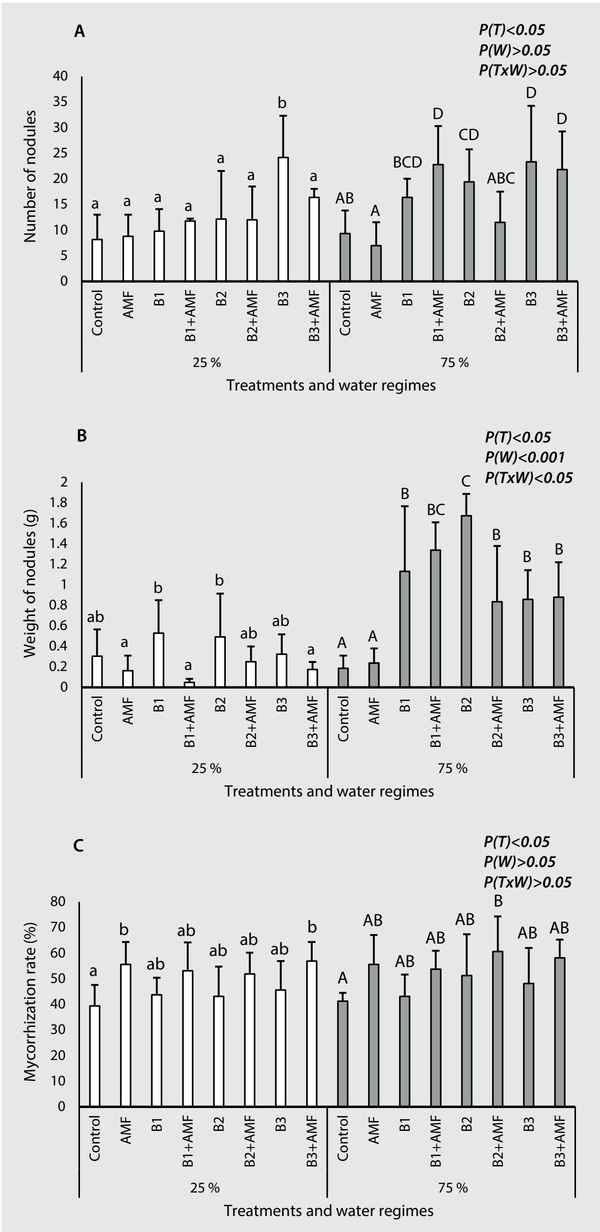


FIGURE 5

Number of nodules (A), weight of nodules (B) and mycorrhization rate (C) of cowpea plants uninoculated (control) and inoculated with three rhizobial bacteria (*Rhizobium* sp. 32–B1, *Bradyrhizobium elkanii* 57–B2 and *Bradyrhizobium* sp. 63–B3), a mixture of arbuscular mycorrhizal fungi (AMF) and co-inoculated with each bacteria and AMF (B1+AMF, B2+AMF and B3+AMF) subjected to two different water regimes (25 and 75 % of field water capacity). Capped lines are standard deviations. Different lowercase letters indicate significant differences ($P<0.05$) among treatments, within plants under drought stress (25 % of field capacity) and uppercase letters indicate significant differences ($P <0.05$) among treatments, within well-watered plants (75 % of field capacity), according to Duncan´s test

## 4 Discussion

Although cowpea has been referred to as a well-adapted plant to abiotic stress, drought is one of the main concerns in its production. Thus, inoculation with selected rhizobial bacteria and AMF has great potential to reduce the impact of water scarcity (Oliveira et al., 2017). Though, the selection of appropriate combinations of specific AMF and rhizobia is very important to improve the yield of cowpea since the response of a legume host to a given set of AMF-*Rhizobium* partners may or may not be favourable for plant growth depending on the interaction of symbionts (Xavier and Germida, 2003). In fact, Ahmad (1995) demonstrated that symbiotic effectiveness depends on a combination of AMF species, *Rhizobium strain*, and also the host plant.

In our work, the inoculation and co-inoculation with the studied microorganisms influenced the plant performance mainly under drought stress. In well-watered plants, the beneficial effects of the inoculation were less evident. This could be due to the presence of other native bacteria and fungi in the soil that also interact with plants, giving them the advantages of symbiosis, even in control plants. However, some differences between control and inoculated plants under drought stress could be observed, suggesting that the native microorganisms present in the soil were not so resistant to drought as the inoculated strains. As shown in other studies, drought, among other stresses, affects the ability to grow and even the basic survival of native microorganisms (Haruta and Kanno, 2015; Goufo et al., 2017).

In general, in plants under drought stress, single inoculation with the studied microorganisms did not improve their responses; however, when both microorganisms were inoculated together, an improvement in the general plant performance was observed. This can be due to the simultaneous improvement in the nitrogen fixation ensured by the bacteria (Hardarson and Atkins, 2003) and the improvement in the uptake of water and other minerals ensured by the fungi (Nadeem et al., 2014). According to previous studies, in general, co-inoculation with rhizobial bacteria and AMF (tripartite symbiosis) improves the water and nutritional status of plants on a larger scale than single inoculation with one microorganism. This can be explained by the fact that nodulation process by rhizobia requires a high amount of P and therefore, the association with AMF helps in the development and function of symbiotic nodules (Ribet and Drevon, 1996). As described in some studies, this symbiosis ameliorates plant photosynthetic efficiency (Jia et al., 2004; Kaschuk et al., 2009) and consequently increases photoassimilate production, which can be used by the plants to improve their growth, productivity, and/or quality. Indeed, the impact that the microbial symbionts have on photosynthetic rates appears to be mediated by their effects on the plant N:P ratio (Jia et al., 2004).

In the present study, co-inoculation did not affect the growth of plants, taking in account the absence of significant differences in the shoot and root weight between control and co-inoculated plants. In line with this, Diallo et al. (2001) found no benefits in plant root and shoot biomass with AMF inoculation. The authors attributed this lack of effect to the fact that the production of fungal mycelium is much more cost-effective in terms of organic carbon (C) than the production of equivalent root length. Consequently, plants adjust belowground C allocation contributing to the formation of a shorter mycorrhizal root system, relying on the fungal mycelium for nutrient uptake (Smith et al., 2000).

Moreover, in the present study, co-inoculations also did not influence the productivity parameters since the number and weight of seeds were not affected, except for the mix of B1 and AMF that resulted in heavier seeds than the control.

We observed a significant increase in the crude protein content (derived from the nitrogen level by the Kjeldahl method) in the seeds of plants under drought stress (25 % of FC) and co-inoculated with one bacteria and AMF in comparison to the control plants, which suggests that these plants have the ability to mobilise photoassimilates to the seed, which is a sink of protein production, in detriment of growth and yield. Despite the increase in nitrogen observed in co-inoculated plants under water stress, it is not possible to distinguish between protein nitrogen and non-protein nitrogen with this method; therefore, it cannot be ruled out that this increase occurred in the non-protein fraction of nitrogen.

In a meta-analysis with 12 legume species performed in a previous study, it was also observed that inoculation with rhizobia in the field and with AMF in pots increased seed protein content (Kaschuk et al., 2010). In fact, according to Dubova et al. (2015), protein accumulation in the seeds depends not only on plant biosynthetic activity but can also be affected by microbial symbionts. From the results of this study, it can be concluded that the microorganisms used in this study were efficient and competitive under drought stress (25 % of FC), benefiting the plants to a greater extent than the native microbiota present in the soil (control plants). In previous studies, it was also shown that these beneficial microorganisms can increase plant resistance to high temperatures and water deficit and that their application can reduce the needs of chemical fertiliser inputs in agriculture (Peoples et al., 1995; Oliveira et al., 2017), as soil microbes are critical for a sustainable functioning of natural and managed ecosystems (Sharma et al., 2018). Additionally to the treatment influence, the crude protein content was also affected by the water regime, being higher in plants under drought stress. This can be explained by the increase in nitrogenous compounds, such as the amino acid proline usually synthesised in large amounts in plants under stress, previously described by da Costa et al. (2011). In fact, proline demonstrates high sensitivity to stress conditions (Ashraf et al., 2011), increasing its concentration by up to 100 times compared to that observed in plants grown under normal conditions (Verbruggen and Hermans, 2008). This increase can occur through de novo synthesis or by inhibiting the oxidation process of proline. The accumulation of proline and other compatible solutes (glycine betaine, trehalose, sucrose, polyamines, mannitol, pinitol and others) in vacuole or cytosol contributes to the maintenance of water balance and the preservation of the integrity of proteins, enzymes, and cell membranes (Marijuan and Bosch, 2013). These solutes also have an osmoprotective function against toxic by-products of metabolism, resulting from water stress. This accumulation is not harmful to cell metabolism and, by increasing the osmotic pressure inside the cells, maintains the water absorption and the turgor pressure of the cells, which allows the continuity of physiological processes (Marijuan and Bosch, 2013). Considerable accumulation of proline is a feature in the response of plants under water stress (Fukutoku and Yamada, 1981; Levy, 1983). Furthermore, water stress induces a net loss of leaf protein since its synthesis is inhibited and its degradation is stimulated, leading to an accumulation of free amino acids (Cooke et al., 1979; Dungey and Davies, 1982). Thus, a relationship between proline accumulation and protein metabolism has been described, since protein may be a source of nitrogen for proline synthesis during water stress. In these conditions, as reported by Fukutoku and Yamada (1984), a loss of leaf protein-$^{15}$N occurs, which is balanced by a gain in $^{15}$N in the free amino acids, namely proline and asparagine.

The use of non-sterilised soil makes this work very useful because we can extrapolate the results obtained in pots to the real conditions in the field. However, it is important to note that the potential of the microorganisms used in this work, especially the fungi, could be underestimated due to the confined space of the pot, which does not allow the maximum development of the root. According to the results obtained in this work, it is possible to extrapolate that the studied bacteria should have the same strategies to cope with stressful conditions, which can be, among others, the formation of cysts and spores, changes in cellular membranes, expression of repair enzymes for damage, synthesis of molecules for relieving stresses (Storz and Hengge, 2011). These strategies make them potentially resistant to drought, which can be used as an improved biotechnological tool for sustainable agriculture in drought situations. Indeed, climate change will seriously impact food security and nutrition, making it crucial to support a transition toward smart and sustainable food systems that take climate into account (FAO, 2008). With this eco-friendly approach, it is possible to increase the nutritional and commercial value of leguminous plants, a cheap and alternative source of protein for human consumption, by increasing their crude protein content without chemical fertiliser applications and genetic improvements.

## Acknowledgements

This research was supported by the European Union's Seventh Framework Program for Research, Technological Development, and Demonstration under Grant Agreement No. 613781, project 'EUROLEGUME: Enhancing of legumes growing in Europe through sustainable cropping for protein supply for food and feed'. This work was also financed by Portuguese national funds through Programa Operacional Competitividade e Internacionalização (POCI), project 3599 Promover a Produção Científica e Desenvolvimento Tecnológico e a Constituição de Redes Temáticas and Fundo Europeu de Desenvolvimento Regional (FEDER) under project POCI-01-0145-FEDER-016801, and by Fundação para a Ciência e

Tecnologia (FCT) under projects PTDC/AGR-TEC/1140/2014 and UID/AGR/04033/2019. Sandra Pereira acknowledges the support provided by the European Social Funds and the Regional Operational Program Norte 2020 (Operation NORTE-08-5369-FSE-000054).

## REFERENCES


Abdel-Fattah GM, El-Haddad SA, Hafez EE, Rashad YM (2011) Induction of defense responses in common bean plants by arbuscular mycorrhizal fungi. Microbiol Res 166(4):268–281, doi:10.1016/j.micres.2010.04.004

Ahmad MH (1995) Compatibility and coselection of vesicular-arbuscular mycorrhizal fungi and rhizobia for tropical legumes. Crit Rev Biotechnol 15(3–4):229–239, doi:10.3109/07388559509147410

Alkama N, Bi Bolou EB, Vailhe H, Roger L, Ounane SM, Drevon JJ (2009) Genotypic variability in P use efficiency for symbiotic nitrogen fixation is associated with variation of proton efflux in cowpea rhizosphere. Soil Biol Biochem 41(9):1814–1823, doi:10.1016/j.soilbio.2008.11.017

Allen ON, Allen EK (1981) The Leguminosae. A source book of characteristics, uses and nodulation. Madison: University of Wisconsin Press, 812 p

Altschul SF, Gish W, Miller W, Myers EW, Lipman DJ (1990) Basic local alignment search tool. J Mol Biol 215(3):403–410, doi:10.1016/s0022-2836(05)80360-2

Antunes PM, Goss MJ (2005) Communication in the tripartite symbiosis formed by arbuscular mycorrhizal fungi, rhizobia and legume plants: a review. In: Zobel RW, Wright SF (eds) Roots and soil management: Interactions between roots and the soil. Vol. 48. Chapter 11. Madison: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 199–222, doi:10.2134/agronmonogr48.c11

Appunu C, N'Zoue A, Moulin L, Depret G, Laguerre G (2009) *Vigna mungo*, *V. radiata* and *V. unguiculata* plants sampled in different agronomical-ecological-climatic regions of India are nodulated by *Bradyrhizobium yuanmingense*. Syst Appl Microbiol 32(7):460–470, doi:10.1016/j.syapm.2009.05.005

Ashraf M, Akram NA, Al-Qurainy F, Foolad MR (2011) Drought tolerance: roles of organic osmolytes, growth regulators, and mineral nutrients. Adv Agron 111:249–296, doi:10.1016/B978-0-12-387689-8.00002-3

Augé RM, Kubikova E, Moore JL (2001) Foliar dehydration tolerance of mycorrhizal cowpea, soybean and bush bean. New Phytol 151:535–541, doi:10.1046/j.0028-646x.2001.00187.x

Bastos EA, Nascimento SP, Silva EM, Freire Filho FR, Gomide RL (2011) Identification of cowpea genotypes for drought tolerance. Rev Ciênc Agron 42(1):100–107, doi:10.1590/S1806-66902011000100013

Bezerra FML, Araripe MAE, Teófilo EM, Cordeiro G, Santos JJA (2003) Cowpea submitted to water deficit in different growth periods/Feijão caupi e déficit hídrico em suas fases fenológicas. Rev Ciênc Agron 34(1):13–18

Carvalho M, Lino-Neto T, Rosa E, Carnide V (2017) Cowpea: a legume crop for a challenging environment. J Sci Food Agric 97(13):4273–4284, doi:10.1002/jsfa.8250

Chalk PM, Souza RDF, Urquiaga S, Alves BJR, Boddey RM (2006) The role of arbuscular mycorrhiza in legume symbiotic performance. Soil Biol Biochem 38(9):2944–2951, doi:10.1016/j.soilbio.2006.05.005

CNV (2019) Catálogo nacional de variedades de espécies agrícolas e hortícolas [online]. Lisboa: Direção Geral de Alimentação e Veterinária. Ministérios da Agricultura e Desenvolvimento Rural, Portugal. Received from <https://dica.madeira.gov.pt/images/DICA/2019/326/CNVariedades_2019.pdf> [at 5 Nov 2020]

Cooke RJ, Oliver J, Davies DD (1979) Stress and protein turnover in *Lemna minor*. Plant Physiol 64(6):1109–1113, doi:10.1104%2Fpp.64.6.1109

Cruz de Carvalho MH (2000) Etude physiologique, biochimique et moléculaire de la réponse à la sécheresse chez *Phaseolus vulgaris* L. et *Vigna unguiculata* L. Walp. Paris, University Paris, 206 p, Thesis. Received from <http://hdl.handle.net/10068/880621> [at 5 Nov 2020]

da Costa RCL, Lobato AKS, Silveira JAG, Laughinghouse HD (2011) ABA-mediated proline synthesis in cowpea leaves exposed to water deficiency and rehydration. Turk J Agric For 35:309–317, doi:10.3906/tar-0911-409

Diallo AT, Samb PI, Roy-Macauley H (2001) Water status and stomatal behaviour of cowpea, *Vigna unguiculata* (L.) Walp., plants inoculated with two *Glomus* species at low soil moisture levels. Eur J Soil Biol 37(3):187–196, doi:10.1016%2FS1164-5563(01)01081-0

Dubova L, Šenberga A, Alsina I (2015) The effect of double inoculation on the broad beans (*Vicia faba* L.) yield quality. Res Rural Dev 215(1):34–39

Dungey NO, Davies DD (1982) Protein turnover in isolated barley leaf segments and the effect of stress. J Exp Bot 33(132):12–20

FAO (2008) The state of food and agriculture. Biofuels: prospects, risks and opportunities [online]. Rome: FAO, 128 p. Received from <www.fao.org/publications/sofa/2008/en/> [at 13 March 2020]

FAOSTAT (2017) [online]. Retrieved from <www.fao.org/faostat/en/#home> [at 13 March 2020]

Fukutoku Y, Yamada Y (1981) Sources of proline-nitrogen in water-stressed soybean (*Glycine max* L.). I. Protein metabolism and proline accumulation. Plant Cell Physiol 22(8):1387–1404, doi:10.1093/oxfordjournals.pcp.a076292

Fukutoku Y, Yamada Y (1984) Sources of proline-nitrogen in water-stressed soybean (*Glycine max*). II. Fate of $^{15}$N-labelled protein. Physiol Plant 61(4):-622–628, doi:10.1111/j.1399-3054.1984.tb05180.x

Gaunt MW, Turner SL, Rigottier-Gois L, Lloyd-Macgilp SA, Young JPW (2001) Phylogenies of atpD and recA support the small subunit rRNA-based classification of rhizobia. Int J Syst Evol Microbiol 51(Pt 6):2037–2048, doi:10.1099/00207713-51-6-2037

Goufo P, Moutinho-Pereira JM, Jorge TF, Correia CM, Oliveira MR, Rosa EAS, António C, Trindade H (2017) Cowpea (*Vigna unguiculata* L. Walp.) Metabolomics: Osmoprotection as a physiological strategy for drought stress resistance and improved yield. Front Plant Sci 8:586, doi:10.3389/fpls.2017.00586

Grewal KS, Buchan GD, Tonkin PJ (1990) Estimation of field capacity and wilting point of some New Zealand soils from their saturation percentages. New Zeal J Crop Hort Sci 18(4):241–246, doi:10.1080/01140671.1990.10428101

Halilou O, Hamidou F, Taya BK, Mahamane S, Vadez V (2015) Water use, transpiration efficiency and yield in cowpea (*Vigna unguiculata*) and peanut (*Arachis hypogaea*) across water regimes. Crop Pasture Sci 66(7):715–728, doi:10.1071/CP14182

Hall AE (2012) Phenotyping cowpeas for adaptation to drought. Front Physiol 3:155, doi:10.3389/fphys.2012.00155

Hamidou F, Zombre G, Diouf O, Diop NN, Guinko S, Braconnier S (2007) Physiological, biochemical and agromorphological responses of five cowpea genotypes (*Vigna unguiculata* (L.) Walp.) to water deficit under glasshouse conditions. Biotechnol Agron Soc Environ 11(3):225–234

Hardarson G, Atkins C (2003) Optimising biological $N_2$ fixation by legumes in farming systems. Plant Soil 252:41–54, doi:10.1023/A:1024103818971

Harrison MJ (1998) Development of the arbuscular mycorrhizal symbiosis. Curr Opin Plant Biol 1(4):360–365, doi:10.1016/1369-5266(88)80060-8

Haruta S, Kanno N (2015) Survivability of microbes in natural environments and their ecological impacts. Microbes Environ 30(2):123–125, doi:10.1264/jsme2.ME3002rh

Haukka K, Lindström K, Young JP (1998) Three phylogenetic groups of *nod*A and *nif*H genes in *Sinorhizobium* and *Mesorhizobium* isolates from leguminous trees growing in Africa and Latin America. Appl Environ Microbiol 64(2):419–426, doi:10.1128/AEM.64.2.419-426.1998

Iqbal A, Khalil IA, Ateeq N, Sayyar Khan M (2006) Nutritional quality of important food legumes. Food Chem 97(2):331–335, doi:10.1016/j.foodchem.2005.05.011

Jia Y, Gray VM, Straker CJ (2004) The influence of *Rhizobium* and arbuscular mycorrhizal fungi on nitrogen and phosphorus accumulation by *Vicia faba*. Ann Bot 94(2):251–258, doi:10.1093/aob/mch135

Johnson JM, Houngnandan P, Kane A, Sanon KB, Neyra M (2013) Diversity patterns of indigenous arbuscular mycorrhizal fungi associated with rhizosphere of cowpea (*Vigna unguiculata* (L.) Walp.) in Benin, West Africa. Pedobiologia (Jena) 56(3):121–128, doi:10.1016/j.pedobi.2013.03.003

Kaschuk G, Leffelaar PA, Giller KE, Alberton O, Hungria M, Kuyper TW (2010) Responses of legumes to rhizobia and arbuscular mycorrhizal fungi: A meta-analysis of potential photosynthate limitation of symbioses. Soil Biol Biochem 42(1):125–127, doi:10.1016/j.soilbio.2009.10.017

Kaschuk G, Leffelaar PA, Kuyper TW, Hungria M, Giller KE (2009) Are rates of photosynthesis stimulated by the carbon sink strength of rhizobial and arbuscular mycorrhizal symbioses? Soil Biol Biochem 41(6):1233–1244, doi:10.1016/j.soilbio.2009.03.005

Krouma A (2010) Plant water relations and photosynthetic activity in three Tunisian chickpea (*Cicer arietinum* L.) genotypes subjected to drought. Turk J Agric For 34(3):257–264, doi:10.3906/tar-0904-1

Laguerre G, Nour SM, Macheret V, Sanjuan J, Drouin P, Amarger N (2001) Classification of rhizobia based on *nod*C and *nif*H gene analysis reveals a close phylogenetic relationship among *Phaseolus vulgaris* symbionts. Microbiology 147(4):981–993, doi:10.1099/00221287-147-4-981

Lazaridi E, Ntatsi G, Savvas D, Bebeli PJ (2017) Diversity in cowpea (*Vigna unguiculata* (L.) Walp.) local populations from Greece. Genet Resour Crop Ev 64:1529–1551, doi:10.1007/s10722-016-0452-6

Levy D (1983) Water deficit enhancement of proline and α-amino nitrogen accumulation in potato plants and its association with susceptibility to drought. Physiol Plant 57(1):169–173, doi:10.1111/j.1399-3054.1983.tb00749.x

Marijuan MP, Bosch SM (2013) Ecophysiology of invasive plants: osmotic adjustment and antioxidants. Trends Plant Sci 18(12):660–666, doi:10.1016/j.tplants.2013.08.006

Marulanda A, Barea JM, Azcón R (2006) An indigenous drought-tolerant strain of Glomus intraradices associated with a native bacterium improves water transport and root development in Retama sphaerocarpa. Microb Ecol 52(4):670–678, doi:10.1007/s00248-006-9078-0

McGonigle TP, Miller MH, Evans DG, Fairchild GL, Swan JA (1990) A new method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. New Phytol 115(3):495–501, doi:10.1111/j.1469-8137.1990.tb00476.x

Nadeem SM, Ahmad M, Zahir ZA, Javaid A, Ashraf M (2014) The role of mycorrhizae and plant growth promoting rhizobacteria (PGPR) in improving crop productivity under stressful environments. Biotechnol Adv 32(2): 429–448, doi:10.1016/j.biotechadv.2013.12.005

Ngalamu T, Odra J, Tongun N (2014) Cowpea production handbook. Juba: IFS/AGRA, Afristar Publishing House, 46 p

Oliveira RS, Carvalho P, Marques G, Ferreira L, Pereira S, Nunes M, Rocha I, Ma Y, Carvalho MF, Vosátka M, Freitas H (2017) Improved grain yield of cowpea (*Vigna unguiculata*) under water deficit after inoculation with *Bradyrhizobium elkanii* and *Rhizophagus irregularis*. Crop Pasture Sci 68(11):1052–1059, doi:10.1071/CP17087

Peoples MB, Herridge DF, Ladha JK (1995) Biological nitrogen fixation: An efficient source of nitrogen for sustainable agricultural production? Plant Soil 174:3–28, doi:10.1007/BF00032239

Ravelombola WS, Shi A, Weng Y, Motes D, Chen P, Srivastava V, Wingfield C (2016) Evaluation of total seed protein content in eleven Arkansas cowpea (*Vigna unguiculata* (L.) Walp.) lines. Am J Plant Sci 7(15):2288–2296, doi:10.4236/ajps.2016.715201

Ribet J, Drevon JJ (1996) The phosphorus requirement of N*2*-fixing and urea-fed *Acacia mangium*. New Phytol 132(3):383–390, doi:10.1111/j.1469-8137.1996.tb01858.x

Sharma L, Gonçalves F, Oliveira I, Torres L, Marques G (2018) Insect-associated fungi from naturally mycosed vine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae). Biocontrol Sci Technol 28(2):122–141, doi: 10.1080/09583157.2018.1428733

Smith FA, Jakobsen I, Smith SE (2000) Spatial differences in acquisition of soil phosphate between two arbuscular mycorrhizal fungi in symbiosis with *Medicago truncatula*. New Phytol 147(2):357–366, doi:10.-1046/j.1469-8137.2000.00695.x

Spilker T, Baldwin A, Bumford A, Dowson CG, Mahenthiralingam E, LiPuma JJ (2009) Expanded multilocus sequence typing for burkholderia species. J Clin Microbiol 47(8):2607–2610, doi:0.1128/jcm.00770-09

Storz G, Hengge R (2011) Bacterial stress Responses. 2nd edition. Washington, DC: ASM Press, 580 p

Vejsadova H, Siblikova D, Gryndler M, Simon T, Miksik I (1993) Influence of inoculation with *Bradyrhizobium japonicum* and *Glomus claroideum* on seed yield of soybean under greenhouse and field conditions. J Plant Nutr 16(4):619–629, doi:10.1080/01904169309364561

Verbruggen N, Hermans C (2008) Proline accumulation in plants: a review. Amino Acids 35:753–759, doi:10.1007/s00726-008-0061-6

Vierheilig H, Coughlan AP, Wyss U, Piché Y (1998) Ink and vinegar, a simple staining technique for arbuscular-mycorrhizal fungi. Appl Environ Microbiol 64(12):5004–5007, doi:10.1128/AEM.64.12.5004-5007.1998

Weisburg WG, Barns SM, Pelletier DA, Lane DJ (1991) 16S ribosomal DNA amplification for phylogenetic study. J Bacteriol 173(2):697–703, doi:10.1128/jb.173.2.697-703.1991

Xavier LJC, Germida JJ (2003) Bacteria associated with *Glomus clarum* spores influence mycorrhizal activity. Soil Biol Biochem 35(3):471–478, doi:10.1016/S0038-0717(03)00003-8

Xie ZP, Staehelin C, Vierheilig H, Wiemken A, Jabbouri S, Broughton WJ, Vogeli-Lange R, Boller T (1995) Rhizobial nodulation factors atimulate mycorrhizal colonization of nodulating and nonnodulating soybeans. Plant Physiol 108(4):1519–1525, doi:10.1104/pp.108.4.1519

Zhang YF, Wang ET, Tian CF, Wang FQ, Han LL, Chen WF, Chen WX (2008) *Bradyrhizobium elkanii*, *Bradyrhizobium yuanmingense* and *Bradyrhizobium japonicum* are the main rhizobia associated with *Vigna unguiculata* and *Vigna radiata* in the subtropical region of China. FEMS Microbiol Lett 285(2):146–154, doi:10.1111/j.1574-6968.2008.01169.x

Zhang YM, Tian CF, Sui XH, Chen WF, Chen WX (2012) Robust markers reflecting phylogeny and taxonomy of rhizobia. PLOS ONE 7(9): e4493, doi:10.1371/journal.pone.0044936

REVIEW ARTICLE

# Policies for agroecology in France: implementation and impact in practice, research and education

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Received: April 22, 2020
Revised: September 2, 2020
Accepted: September 10, 2020

HIGHLIGHTS

- **France is the first country having a law for agroecology and related policies.**
- **Success in more implementation of agroecological practices, and more conversion to organic agriculture.**
- **Failure on the reduction of pesticide use.**
- **Quicker and stronger implementation of education and training, and increased agroecology related research.**

KEYWORDS **agricultural policy, policy tools, agroecological practice, organic agriculture, sustainable agriculture, training and higher education**

## Abstract

The challenge of feeding the growing world population while reducing the adverse environmental effects of agriculture will only be met by combining fundamental changes in agricultural and food systems. France is considered to be one of the first countries to develop policies in agroecology and translate them into concrete programmes and laws. This paper analyses the historical development of different agroecology-related programmes and policies and their implementation. It discusses whether they have made an impact and considers the obstacles and resisting forces that have become apparent. The work reported here is mainly based on literature review using scientific papers and grey literature and web source analysis as well using informal discussion with experts. The policy for agroecology started in 2010 with wide ranging debates about challenges for agriculture in France in preserving natural resources and developing an economically viable and socially acceptable agricultural system. In 2012, the French Ministry of Agriculture and Food launched the “Agroecological Project for France” supporting education, research and incentives for farmers to move forward with agroecology. Within this general project different sectoral programmes were set up and launched, addressing farming practices and innovation led by individuals or farmer groups. These also looked at incentivising research in national research programmes. New agricultural curricula for high schools and higher education institutions were also included in the scope of the project. The policy initiated in 2010 resulted in acceleration and stronger implementation of education and training, and in increased research focussing on certain topics. It also stimulated a certain ‘transition’ in the agricultural sector with a wider acceptance of agroecological approaches. It brought forward pioneers which stimulated innovation based on agroecological principles. The policy measures aimed directly at farmers have facilitated more implementation of agroecological practices, stronger recognition of the importance of biodiversity for agriculture, and increased conversion to organic agriculture regardless of the farming system. However, the French policies have failed to reduce the use of pesticides in conventional agriculture. The policy development at national level was supplemented by French initiatives at European and international level to introduce more agroecology components and principles in future policies.

## 1 Introduction

Feeding the currently predicted global population of $9 \times 10^9$ people in 2050 is a growing challenge in the context of climate change, land degradation, biodiversity loss, access to food, food waste, food scarcity and insecurity. These challenges come conversely with over-consumption and unbalanced diets that raise the incidences of chronic diseases affecting human health. There are strongly contrasting and highly diverse views on how to overcome these challenges and which avenues to take for the best management of future

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agriculture and food systems. Different scenarios explored the range of possibilities of feeding the projected 2050 world population by varying agricultural intensification, livestock feed composition and changes to human diet. These demonstrate that a large range of options exist without expanding the global agricultural area (Paillard et al., 2010; Couturier et al., 2017). In this respect, agroecology offers potential solutions to design sustainable agricultural and food systems and credible options to address food and environmental challenges through adoption of farming and food systems that are environmentally sound, social just, and economic viable (Muller et al., 2017; Poux and Aubert, 2018).

The term 'agroecology' was first used at the end of the 1920s (Wezel and Soldat, 2009). Since then, its meaning, definition, interpretation and approach have changed enormously up to the present. Agroecology as a scientific discipline developed slowly in the 1930s to 1960s. From the 1970s onwards, interpretations of agroecology expanded and diversified. Agroecology as a movement gradually emerged in the 1970s in addition to being a scientific discipline, and consecutively also being seen as a set of practices beginning in the 1980s (Wezel et al., 2009). Agroecology's historical evolution covers a transition from addressing the plot and field scales (1930s to 1960s) to the farm and agroecosystem scales (1970s to 2000s) (Wezel and Soldat, 2009). It has now been extended to encompass the wider dimensions of the food system (Francis et al., 2003; Gliessman, 2007).

The foundation of the agroecological movements in the 1960s and 70s were laid within the environmental movements which opposed the negative impacts of industrialised agriculture that came with the Green Revolution. In particular, the negative consequences of agricultural chemical use were highlighted. This pointed at the adverse impacts of pesticides or other toxic substances on fauna and flora and other natural resources. While more environmentally-sound approaches were advocated by environmentalists, the movement did not relate directly to the term 'agroecology' before the 1990s. Agroecology became more associated with specific agricultural and social movements in the 1990s, especially in Latin America, where the term was used to express a new way of considering agriculture and its relationships with society promoting family farming systems and food sovereignty.

Since the 1980s, a third usage of the term 'agroecology' has emerged beyond that of a science and movement. This describes a set of agricultural practices aiming at maximising the use of ecological processes in the functioning of agroecosystems. Local farmers, supported by an agroecological approach, sought to improve and adopt farming practices that do not rely anymore, or to a decreased extent, on the widespread use of chemical inputs (fertilisers, pesticides) that are used in intensive systems (see Altieri 1989, 1995; Gliessman, 2007). Conserving natural resources is the basis. This involves implementing best soil fertility management practices and favouring and enhancing agrobiodiversity on fields and farms. These practices included intercropping, cover crops, diversified rotations, no or reduced tillage, biological control, mixed crop-livestock systems and integration of semi-natural landscape elements supporting functional biodiversity (Arrignon, 1987; Altieri, 1989, 1995; Gliessman, 2007, IAASTD, 2009; Wezel et al., 2014a, 2014b).

In recent years, agroecology is increasingly seen as being able to contribute to transforming the whole agri-food systems by applying ecological principles in many dimensions such as in fertility management, plant and animal production, land use, non-food uses, and human diets. Applying the principles of agroecology to agri-food systems must be understood in relation to address simultaneously issues relating to health, food security, the protection of natural resources and biodiversity, and climate mitigation (Francis et al., 2003; Gliessman, 2007; Fritz and Schiefer, 2008; Wezel and David, 2012; Wezel et al., 2015; HLPE, 2019). At the same time, and indivisible from respecting ecological principles, it is the imperative to consider social and cultural aspects in developing equitable food systems within which all people can exercise choice over what they eat and how and where it is produced. This means that all people have sovereignty in meeting their food and nutrition requirements. Today, agroecology combines science, practice and a social movement. These complement each other, although they may not all remain in step with one another and efforts will be required to ensure effective collaboration between these components. Moreover, different policies are emerging in recent years that aim at supporting the development of agroecology in its different forms. They are mostly not yet specifically called agroecology policies but use other terms. The current negotiations on the new Common Agricultural Policy (CAP) in Europe for the period 2021 to 2027 with the 'Farm to Fork' strategy and the New Green Deal reflect debates related to agroecology even it is considered by some incompatible with tackling other crucial challenges: producing enough for Europe and the world while developing bioeconomy sectors in Europe (EC, 2018). For instance, the agroecology ten year scenario addresses this apparent dilemma by examining how much feed/food/fuel and other materials the agricultural sector could and should produce to tackle, with equal priority, challenges associated with climate change, health, the protection of biodiversity and natural resources, and the provision of a sustainable and healthy diet to Europeans without affecting global food security (Poux and Aubert, 2018).

In this paper we start with a short overview about agroecology from a European perspective before providing a description of the French case, describing instruments and policies and their implementation to support agroecology. We finally discuss the success of these policies and obstacles or hindering forces that have become apparent. The work is mainly based on review of scientific journal papers and of the grey literature. The section on policy instruments also draws on information from web sources, and on informal discussions with French and European experts. The judgement about success or failure is the judgement of the authors.

## 2 European context

At the European scale, there has been so far no clear EU strategy for agroecology and sustainable agriculture even if some recent discussions draw on the notion of agroecology (e.g the

Farm to Fork strategy). Consequently, national programmes, policies or action plans for agroecology are rare in Europe (currently only France, Denmark and Italy mention agroecology in their policies) and these differ widely. With the new CAP, the European Commission established a policy of 'Greening' in 2014 which requires limited agroecological practices for all direct payments. These practices encompass establishment of ecological focus areas on five percent of the agricultural land (e.g. hedgerows and other diverse habitats, but also cover crops), crop diversification on farms, and restriction on converting permanent grassland into cropland (EC, 2013; Niggli, 2015). The CAP for 2014 to 2020 included valuable elements, in addition to already existing agri-environment measures, but with limited funding and implementation so far. However, the debates on the new CAP 2021 to 2027 in Europe increasingly include discussions related to agroecology. So far, France is the only country among the EU member states to have set up an explicit "Agroecological Project for France" strategy in December 2012 (Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2016a).

More recently, in May 2020, the EU Commission launched two strategies which include different elements of agroecology. The 'Farm to Fork' strategy sets ambitious objectives for example to reduce chemical pesticides by 50 %, reduce fertiliser use by at least 20 %, and achieve 25 % of total farmland and organic farming, all by 2030 (EC, 2020a). The new EU Biodiversity Strategy includes also these points and adds others such as increasing biodiversity-rich landscape elements on agricultural land, and halting and reversing the decline of pollinators (EC, 2020b).

## 3 Agroecology in France

### 3.1 Agroecology policy

In 2012, the government of France defined agroecology as the general principle of agricultural practice, supported by different laws applied to agriculture, food and forestry ('Loi d'avenir', launched on October 2014). However, the implementation of policies for agroecology in France started more than a decade ago, but without calling them agroecological at that time. The different programmes and elements include the Grenelle Environment Forum, a debate and consultation process, the Ecophyto programme, the French response to the EU Framework Directive on the sustainable use of chemical plant protection products, the Ambition Bio programme for strong development of organic agriculture, and more recently a law to promote balanced commercial relationships in the agricultural and food sector and healthy, sustainable food.

#### 3.1.1 Grenelle Environment Forum

In 2007, the French government lead by a coalition of the conservative and liberal parties (under President Nicolas Sarkozy) launched a national debate called Grenelle de l'Environnement (Grenelle Environment Forum) bringing together the government, state and representatives of civil society to draw up a road map for the environment and sustainable development (*Figure 1*). The notion of 'agroecology' was first mentioned during a Forum meeting in October 2007 when the impact of climate change and loss of biodiversity in agriculture was discussed. Before that, the debate on agriculture in France remained dominated by macro- and micro-institutions that put food availability and agricultural production at the heart of the problem and solutions. Environmental issues were not given priority by governments for a long time. The Grenelle Environment Forum consultation process in 2007 was followed by further discussion and proposals until the new French president and government elections in 2012. The consultation process involved a large group consisting of farmers, trade unions, representatives of agri-food companies, non-governmental organisations, local authorities and public service representatives to work out policy measures. A further objective of the Forum was to establish an action plan of concrete and quantifiable measures that would be met with the broadest possible agreement among participants. Topics selected were climate change, biodiversity, environment and health, sustainable production and consumption, environmental democracy, and environmental growth and economic instruments (ESEC, 2012). The role of agriculture in relation to these topics was an important part of the debate. Some of the major achievements of the Forum include stakeholders' consensus in almost all the fields of environmental protection, and agreement that the government should adopt and implement stronger laws that reflect the final decisions adopted by the Grenelle Forum. Corporate Social and Environmental Responsibility was emphasised. The Forum also provided a platform for exchange and discussion for key actors of the civil society. One outcome was that new bilateral relations, e.g. between NGOs and unions or NGOs and local governments, have been created and developed.

#### 3.1.2 Ecophyto – national action plan to reduce pesticide use

The Ecophyto 2018 programme was set up in 2008, just after the start of the Grenelle Forum, to reduce the use of pesticide by 50 % by 2018. The aim was train farmers and to inform them about alternatives to chemical inputs. A reference indicator was defined through active discussions between experts, representatives of agrochemical companies, civil society, and official state agencies. This indicator calculates the number and quantity of active ingredients in products, and assesses the usage intensity of plant protection active substance. Its purpose is to monitor pesticide use and progress in reduction. Since the start of the Ecophyto programme in 2008 several actions have been carried out with i) a pilot farm network that brings together 3000 farms working with alternative methods to reduced or avoided pesticide use, ii) an experimental farm network of 41 sites including 170 experimental sites testing and then demonstrating agroecological practices that do not use pesticides, iii) a strong network of higher education institutions and colleges (128 colleges of agricultural science and 3 universities of agriculture and food science decided to convert their experimental facilities to implement and test agroecology practices) with specific programmes on agroecological practices, and iv) continuous education programmes and training for current or future practitioners.

### 3.1.3 Action programmes for organic agriculture

The first Organic Action Plan was launched by the former Minister of Agriculture, Michel Barnier in 2007. The five-year programme aimed to increase organic production in France to cover the national demand. It also aimed to promote research and education programmes. This reflected the fact that France ranked 13 in Europe in terms of organic food production in 2006 with 50 % of consumption met by imports. Organic production covered less than 2 % of Utilised Agricultural Land (UAL) and accounted for 2 % of French farms in 2007. Organic production doubled by 2013 with 4 % of UAL and 5.3 % of French farmers practising organic agriculture. This first action programme can be considered as a success by doubling production area and number of organic farms. But consumer demand continued to increase due to a massive increase in the number of regular and occasional consumers of organic products in the supermarket (from 24 % to 40 %). Consequently, supermarkets built their expansion of organic products on imports to compensate the lack of national production. In response to this, a new organic action plan called "Ambition Bio 2017" was set up in 2012. It introduced direct payments for organic farmers and higher payments during the conversion, financial support for supply chain actors, more funds for research and dissemination, better training and education of farmers and supply chain actors, and more communication on public services to achieve a 20 % share for organic products in public catering. By 2017, the organic production had increased to 6.5 % of UAL and 8.2 % of farms. However, the ongoing increasing demand of organic food in France and Europe led policy makers to set up a further programme to support transition towards more organic production to cover increasing national and international demands. The Organic Ambition 2022 plan was launched in 2018 with the ambition to reach 15 % of UAL under organic by 2022 and a share of 20 % organic products in public catering. The massive increase of consumer demand during the last fifteen years led to the setting up of regular programmes to support organic production and consumption.

### 3.1.4 The 'Agroecological Project for France' supported by the new 'Law for the Future of Agriculture, Food and the Forest'

In 2012 the French Ministry of Agriculture launched the 'Agroecological Project for France' strategy (Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2016a). This strategy was the start of an explicit policy in favour of agroecology. In 2014, France was the first country in the world to set up a law for agroecology, with the ambition of applying agroecology to 200,000 farms by 2025. This law, 'Loi d'Avenir' (Law for the Future of Agriculture, Food and the Forest), which was adopted in October 2014, includes agroecology as a solution to current problems in the agricultural sector. The law states that 'public policies aim to promote and sustain agroecological production systems, including organic production, which combine economic and social performance, particularly through a high level of social, environmental and health protection. More specifically, the notions of 'agroecological model' and 'agroecological measures' are mentioned in the law in Article L1, Section II of the 'Code Rural et de la Pêche Maritime' (Rural and Marine Fishery Codex), that defines the objectives of policy support for agriculture,

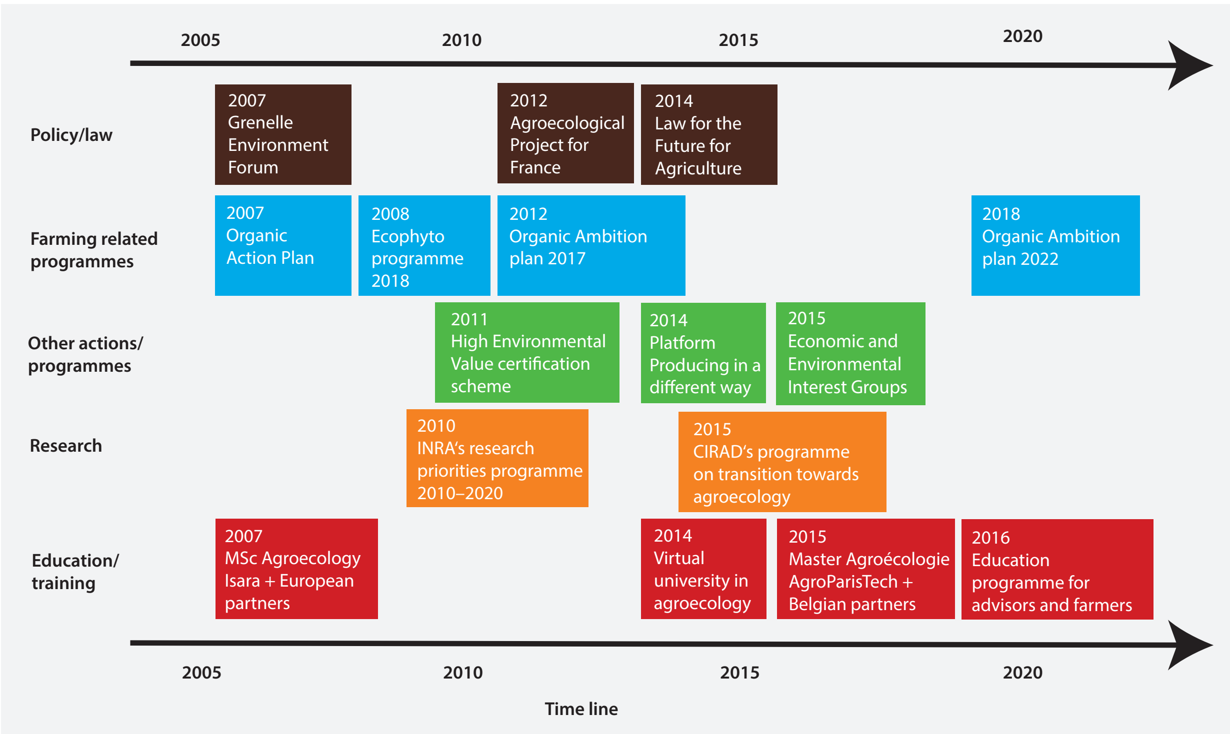


FIGURE 1
Time line of policies and programmes for agroecology in France

food and marine fisheries (Légifrance, 2017). This integration of agroecology into law is remarkable as "agroecology represents a revolution when considered in relation to the dominant agricultural production model. It claims to produce based on the functionality of ecosystems, and not by using inputs to fight environmental constraints" (Hermon, 2015).

One concrete first action in 2014 was the employment of over 200 new researchers and tutors by the French state to teach agroecology across the country as a core part of the national agricultural educational programme (Crosskey, 2014). In addition, the agroecology policy and law were implemented to address growing concern about France's ageing farmers. Forecasts showed that about 40 % of France's agricultural workforce would retire within five years or were already past retirement age. This created a pressing need to train a new generation of farmers who can take over farms and create more jobs in the sector. Soil protection is therefore a high-priority issue for France, especially in terms of the preservation of farmland and the implementation of policies and measures for carbon enrichment and sequestration in soils. In this context, France specifically advocates the '4 per 1,000 initiative: Soils for Food Security and Climate'.

In addition to the national project for agroecology launched by the French minister of agriculture in 2012, an international plan focused on the FAO was added in 2014 (Loconto and Fouilleux, 2019).

### 3.1.5 Programmes and platforms supporting the 'Agroecology Project for France'

**Agroecology platforms**

Different programmes and platforms supported the 'Agroecology Project for France'. One platform was 'Agricultures: Producing in a different way' which has been launched in 2012 to promote the policy to make France a nation of environmental excellence (Bellon and Ollivier, 2018). This platform existed for a few years but has been placed now under the general website of the French Ministry of Agriculture and Nutrition providing related information (Ministère d'Agriculture et de l'Alimentation, 2019b).

**Economic and Environmental Interest Groups**

The promotion and establishment of Economic and Environmental Interest Groups (in French GIEE), of which 527 have been created since 2015 with 492 still active in 2019 (Ministère de l'Agriculture et de l'Alimentation, 2019c) are tangible outcomes of the new law for 'Future of Agriculture, Food and the Forest' (Section 3.4). These farmer groups including about 8000 farms and 9500 individual farmers were developed to support agroecological initiatives. Farmer groups can apply for the programme and also get some financial support from regional governments. The programme is quite similar to the previous presented Ecophyto policy favouring the implementation of more agroecological practices and supporting the transition of individual farms, education and extension facilities (e.g. experimental sites) to test agroecology. The major topics of the GIEE are i) reduction of pesticide use and use of synthetic fertilisers, ii) feed autonomy of livestock farms, and iii) conservation agriculture practices.

**'High Environmental Value' certification scheme**

The French Ministry of Agriculture launched a policy in 2011 with a new system of 'High Environmental Value' (HVE) certification for agricultural operations to promote their engagement in practices that are especially beneficial for the environment. This encourages farmers to enhance biodiversity conservation, decrease the negative environmental impacts of pesticide use, and improve management of fertiliser inputs and water resources. Farmers need to reason their practices based on agroecological principles at the whole farm level taking into account also the natural area on the farm (Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2016c). It is intended to be complementary to the organic certification and to be seen also as potentially bringing a premium for farmers when marketing these products. In April 2019, the first supermarket chain in France declared the intention to enlarge their products with a HVE certification to favour for the development of agroecology (AgroMedia, 2019). By March 2019, 8 % of family farms dedicated to crop production were involved in the HVE certification scheme. Therefore, the Ministry of Agriculture and Food has recognised 74 territorial food supply action plans in 47 regions. These territorial action plans aim to promote optimum use of local resources – leading to a detailed management of nutrient flows at the territorial level – with the willingness to support dietary change. In particular, diets should contain less animal product (but better quality), less sugar, higher fibre intake and increase consumption of in-season fruit and vegetables.

## 3.2 Research on agroecology

Research in France on agroecology has developed gradually since 2000, in most cases coming from researchers in agronomy who questioned their discipline amidst increasing criticism about environmental and health problems related to agriculture. They saw the need to legitimise the application of ecology to agriculture (Bellon and Ollivier 2018). Since 2010, INRA, renamed INRAE in 2020 (National Research Institute for Agriculture, Food and Environment), has developed a priority programme on agroecology. This has impacted drastically on their strategy (Guillou et al., 2010). For instance, some joint research units, grouping 80 to 150 researchers from various disciplines, are fully dedicated to agroecology (Wezel et al. 2018). These include for example:

- Joint research unit 'Agroecology', consisting of researchers from INRAE Dijon, CNRS Dijon, AgroSup Dijon, and the University of Burgundy, Dijon.
- Joint research unit 'Agroecologies, Innovations and Ruralities', a cooperation of INRAE, ENSAT and INP at Toulouse.
- Joint research unit 'Health and Agroecology of Vineyards' combining researchers from INRAE Bordeaux, Bordeaux Sciences Agro, Institute of Vine & Wine Science, Bordeaux.
- Joint research unit 'Biodiversity, Agroecology and Landscape Management', a cooperation of researchers from Agrocampus Ouest and ESA, Angers, and INRAE, Rennes.

Some of the INRAE research units gradually introduced the name 'agroecology' between 2006 and 2009 (Bellon and Ollivier, 2018). Other institutions followed later.

One example is CIRAD (Agricultural Research for Development), a French applied research institution specialised in the tropics and subtropics, that launched a specific programme on transition towards agroecology in 2015 (Côte et al., 2019). They created a research unit 'Agroecology and Sustainable Intensification of Annual Crops' to develop ecological intensification of cropping systems. Also, Isara, an institute for higher education and research in Lyon, launched a research unit called 'Agroecology and Environment' in 2014 that deals with different research topics in agroecology, and interacts with the social science unit in agroecology and the food systems research. A similar institute for higher education, ESA Angers, has a research unit 'Leguminosae, Plant Ecophysiology, Agroecology'.

A strong reinforcement of agroecology in the French national research agenda started with INRAE's strategic research orientation plan 2010-2020 (INRA, 2010). Agroecology was acknowledged as a new science by INRAE. It was also framed in terms of a joint environmental and economic performance in response to the governmental framing (Guillou et al., 2013; Bellon and Ollivier, 2018). For INRAE and CIRAD, "agroecology is often seen as a cross between ecology and agriculture, aimed at designing and managing sustainable agro-ecosystems. It also draws on economics and social sciences to develop reliable systems and roll them out through appropriate public policy and support mechanisms. Agro-ecology therefore offers a new paradigm for creating sustainable food systems" (INRA and CIRAD, 2016).

### 3.3 Education and training in agroecology

In order to train the future generation of agroecologists, universities and other intuitions of higher education created education programmes in agroecology in Europe. Several of the master programmes (MSc – Master of Science) are international and organised by a consortium of universities from different countries, among them French institutions (see more details in Wezel et al., 2018). Some of these programmes are run as double degrees with two or more universities involved, the first one was created in 2007 (Isara, France – NMBU, Norway). Moving from one university to another allows the student to have a diversified academic and practical (e.g. case studies) experience of agroecology. Moreover, the programmes gather a diversity of nationalities and backgrounds, especially for those taught in English. Another programme with the AgroParisTech and Belgian universities was launched about 8 years later. There are also several French national BSc-level programmes that recently revised their curricula to introduce agroecology concepts with 17 programmes of two years and 8 programmes of three years (Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2014; Ajates Gonzales et al., 2018). In particular, the so-called BTS programmes (more practice-oriented BSc programmes) should include agroecology in their curricula (this was carried out, but without changing the titles of the programmes). Besides the MSc and BSc programmes, there is also a virtual university in agroecology which started in 2014 (UVAE, 2019).

The challenge today is largely about promoting agroecology. Twelve key actions have been set up by the French Ministry of Agriculture to support transition towards agroecology (Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2016b) by 2025 for a majority of French farmers. Education programmes for advisers and farmers were set up in 2016 to disseminate experience from the first pioneers (see section Economic and Environmental Interest Group). Moreover, there is a fund (VIVEA) for training farmers in France. It includes also more specialised training in agroecology in recent years. These are often several-day, highly practical, instructor-led training events. An increasing amount of training in agroecology is now offered by various institutions, associations and NGOs.

## 4 Discussion

In France, agroecology started to become more visible in 2008, mainly due to social movements like Colibris founded in 2006 by Pierre Rahbi and colleagues. These support agrobiodiversity-rich, and fair family-run agriculture (Norder et al., 2016). Curiously, agroecology was also been advocated a bit later by some conventional agri-food business organisations (Bellon and Ollivier, 2011, cited in Norder et al., 2016) to develop a new model between conventional and organic agriculture. Despite this, the concept of agroecology was practically non-existent before 2012 among conventional agriculture organisations and was also criticised by the dominant French agricultural union (FNSEA) working closely with the agricultural chambers (Norder et al., 2016). In contrast, the Confederation Paysanne, the traditionally left-wing agricultural union, has been a staunch supporter of agroecology movements in and outside France such as Via Campesina and has strongly supported small and medium-sized family farms engaged in organic conversion.

One explanation for this is that agroecology was not really a feature of the French agricultural policy debate before 2012. Instead, the terms and concepts of "ecoagriculture" and "ecologically intensive agriculture" predominated (Bellon and Ollivier, 2018). Agroecology gained more legitimacy internationally in preceding years with for example the International Assessment of Agricultural Knowledge, Science and Technology for Development report (IAASTD, 2009) and the right to food report of De Schutter (2010). A further push forward for the visibility of the term agroecology from 2010 onwards in France can be attributed to the launch of INRAE's strategic research orientation plan 2010 to 2020 (INRA 2010), highlighting agroecology in future research.

### 4.1 Impact of policies

The policies and programmes for agroecology developed in France vary greatly in their impacts. The first and stronger impacts can be seen with research and education. New research programmes (both with state funding and funding from foundations) were established with a specific focus on agroecology or on topics that are indirectly related to agroecology. New programmes in agroecology were launched in higher education, although some existed already before policies started, and some high school programmes included agroecology concepts.

For practical application in farming, the Economic and Environmental Interest Group programme has promoted farmers' initiatives to develop and implement agroecological practices such as biological control, cover crops, no till, and organic practices. These interest groups developed rapidly after agroecology became integrated into French law showing that such regulation can be an important catalyst for its development supporting pioneers' implementation of agroecology. Overall, the policies of the 'Agroecology Project for France' remained modest because of limited funding (Bellon and Ollivier, 2018).

**Varied impact with the Ecophyto programme**

The impact of the Ecophyto programme to reduce pesticide use shows quite divergent results. Some advances have been made and positive outcomes can be seen, e.g. the establishment of demonstration cases with pilot farms based on reduced or no use of pesticides and creation of Ecophyto farm networks. This included a network of thousands of farms that test and apply methods that reduce the use of chemical plant protection products, improved national surveillance of pests and plant diseases, and funded research on technologies and techniques that reduce pesticide use. Nearly 500 million Euros has been spent on implementing the Ecophyto programme so far. From 2010 to 2018, the 3000 pilot farms have reduced their pesticide use by 18 % (Ministère de l'Agriculture et de l'Alimentation, 2019a).

Overall, the Ecophyto 2018 policy has critically failed as indicated by an 14 % increase in pesticide use for the whole agricultural sector (Lamichhane et al., 2019). This contrasts with a 38 % decline in use in non-agricultural areas (e.g. public gardens, roads). By 2016 pesticide consumption in France increased by 17 % compared to 2011 (Eurostats, 2018) and the highest ever consumption of pesticides was recorded in 2018 (Eurostats, 2019). The failure of this policy brings to light the dependency of French agriculture on pesticides especially on perennial crops such as grape vines, fruit crops, vegetables and industrial crops. However, in the last two years, the dramatic droughts in France have potentially alerted farmers of the need to limit inputs like pesticides where production is constrained.

**Agroecology is well recognised**

In January 2017, 83 % of farmers interviewed stated that they had heard about agroecology, against 79 % in 2016 and only 50 % in 2015 (Gramond 2015, 2016). Additionally, 73 % of farmers have already engaged in at least three agroecological practices. This was 83 % for young farmers. This indicates that agroecology supports the joint realisation of environmental and economic outcomes that was a leading paradigm for the French agroecology policy, and is now an underlying trend in French agriculture. Nowadays, the major French agricultural union is slowly increasing its support of agroecology but seeing it as a set of practices. This is for example in contrast to the national farmers union in Canada that considers agroecology as a holistic approach to food production that uses social, cultural, economic and environmental knowledge to promote food sovereignty, social justice, economic sustainability, and healthy agricultural ecosystems (National Farmers Union, 2015). The French FNSEA agricultural union also clearly announced that they will support an agroecological transition only if the European Commission and France reconsider the economic dimension of agriculture, with ongoing debates in France and about the new EU CAP.

**Development of organic farming**

There was some growth in the area of agricultural land under organic farming rising from under 2 % in 2006 to 7.5 % in 2018. The number of organic farms rose from 3 % to 9.5 % in the same period (Agence Bio, 2019). Organic agriculture support programmes may have played a role, but markets were the main driver as more consumers as well as the French and international markets demanded more organic products. Moreover, the growing number of farmers converting to organic agriculture resulted in a larger and more diverse offer of organic products of French origin on the national market.

The conflict between conventional and organic production, historically supported by the differing positions of the two major farmers' unions (e.g. the conservative FNSEA farmers' union supported the conventional agricultural model, whereas the Confederation Paysanne supported the organic movement), did not help the development of organic production. Nevertheless, with fears over GM crops, health scandals and crises in agriculture, more consumers are changing their dietary habits, supporting the booming of the organic market since the beginning of the 21th century, in and outside France.

**Ambiguity within agroecology and between agroecology and organic agriculture**

With the launch of the agroecology policy, it became evident that many stakeholders have difficulty seeing how agroecology is different from organic agriculture (Migliorini and Wezel, 2018). For some it is more or less the same, other see large differences. Many 'conventional' farmers see organic agriculture as a clearly different way of farming, involving another way of thinking and conviction. Therefore, there is a risk that some farmers reject agroecology because the agroecology policy includes the promotion of organic agriculture in France. Moreover, most farmers and other stakeholders have difficulty understanding what agroecology is. This is related to different interpretations and definitions, which are in addition differently present in different countries of the world (Wezel et al., 2009; Méndez et al., 2013; Agroecology Europe, 2017; Gliessman, 2018). So, there might be confusion or even rejection when policies are not explicit enough about what they mean by agroecology. The policies in France relate more to certain elements of agroecology, such as agroecological practices and farming systems that jointly improve environmental and economic performance at the production level. For the most part, they do not address elements of the food system, or even transformation of the current food system, which is seen as an essential part of agroecology today (Francis et al., 2003; Gliessman, 2007; Wezel et al., 2015; Ajates Gonzales et al., 2018; Poux and Aubert, 2018; HLPE, 2019). Only recently, the law for Agriculture and Food in 2018 (Ministère de l'Agriculture et de l'Alimentation, 2019d) addressed wider aspects of food systems which is an important component of the larger definition of agroecology (Wezel et al., 2009; Wezel and Soldat, 2009). However, the law does not make a clear link to agroecology and does not even state the term (Legifrance, 2018). It includes sub-points such as i) a target of 50 % of local products or origin- and quality-labelled products (including organic) in the public-sector institutional catering by 2022, or ii) intensification of efforts to control food waste (Ministère de l'Agriculture et de l'Alimentation, 2019d), both which relate to the food systems dimension of agroecology. But other sub-points such as i) a ban on neonicotinoids and other products with identical modes of action in order to protect biodiversity and bees, or ii) a separation of sales activity from advisory services for plant protection products, are much more specific and more advanced compared to the former agroecology law.

Although the discourse of the French Ministry of Agriculture presents agroecology as a new paradigm, the framing of agroecology is intended more to be in tune with public action processes and to gain support for agricultural development policies amongst a large diversity of agri-food stakeholders. This is even associated with more intensive and competitive agricultural models (Ajates Gonzales et al., 2018). The assumption is that to continue to be supported by society, agriculture policy has to clearly demonstrate that it is meeting society's contemporary needs. Social expectations regarding healthy diets, the protection of natural resources and biodiversity are becoming increasingly apparent in France and at the European level. The French government clearly promotes "family-based and sustainable farming to bring about the ecological transition, improvements in agricultural practice to meet the expectations of the public and fair remuneration for the actors involved, all this with the application of the same rules to countries exporting to the European Union" (Ministère de l'Agriculture et de l'Alimentation, 2018). Faced with production and market globalisation, France needs to overcome a number of major challenges regarding the social and economic viability of the agricultural sector. Strong lobbying by French agricultural unions and major companies tend to limit the transition towards a wide ranging agroecological model.

One major difficulty is that so far only organic agriculture is clearly labelled and certified in a way which is visible to consumers. The development of 'high environmental value' (HVE) certification label in France could be a tentative opportunity for future agroecology labelling. This supports the labelling of farms, among them a share of 50 % of independent vine growers. It is less visible so far on other products. These different certifications and the growing number of other public and private certification schemes have led to confusing messages for consumers. For example, there is a more recent development of new guidelines for 'regenerative agriculture' supported by large national and international companies (e.g. Danone, Nestlé) or 'living agriculture' ('agriculture du vivant') supported by a group of French food industry players. Moreover, the search for market recognition with a brand or label integrating the principles of agroecology was led by the INAO (Institut National de l'Origine et de la Qualité) in 2016. But apart from the organic sector, the proposal was contested at this time by most affected organisations (Bellon and Ollivier, 2018). Generally, the private companies' 'living agriculture' and 'regenerative agriculture' labelling/certification schemes and the public certification of HVE certification scheme can be regarded as agroecology schemes designed to support business opportunities. The policy and private trend towards new agroecology certification schemes could create even more confusion with the strong growth of organic certification (Migliorini and Wezel, 2018).

## 4.2 The role of visionary politicians and charismatic leaders

The "Agroecological Project for France" launched in 2014 was strongly promoted by Stéphane Le Foll, Minister of Agriculture and former member of the European parliament and one of the founders of the European think tank Groupe Saint Germain (Guilloux and Denoux, 2014). Edgard Pisani, minister of agriculture from 1961 to 1966, created this think tank. Pisani was a visionary politician and one of the founders of a European policy for agriculture. This charismatic leader focused first on the recognition of family farms and diversity. This was followed by consideration of a better connection between agriculture and citizens' awareness regarding environmental protection and food quality.

The political changeover in 2017 with the new President Emmanuel Macron and the new party has not (yet) induced profound changes despite the departure of the charismatic Stéphane Le Foll from the Ministry of Agriculture. The policies for agroecology continue but are not as visible with new programmes or regulations as they once were. For example, the discussion about a ban of glyphosate has not yet reached a decision. Moreover, many policy debates focus since 2019 more on the new European CAP policy (Ministère de l'Agriculture et de l'Alimentation, 2018). The development of agroecology in France is now surprisingly supported by the large French farming union (FNSEA) although they strongly criticised the organic movement in the past.

## 4.3 Lobbying at international level

France was first in launching a national policy for agroecology. This was quickly followed by policy initiatives at an international level. France played an important role in supporting and promoting agroecology at the FAO and with other initiatives such as the carbon sequestration initiative '4 per 1000' recognised in the world as a prominent and leading initiative to promote agroecology. This initiative, launched in Paris at the COP 21 of the Climate Change Convention, aims to increase the soil organic matter content and carbon sequestration through the implementation of agricultural practices adapted to local environmental, social and economic conditions. This involves in particular agroecology, agroforestry, and conservation agriculture.

Furthermore, France was among the initiators of the first agroecology symposium of the FAO in 2014 and provided significant funding (Loconto and Fouilleux, 2019). Moreover, France is member of the Friends of Agroecology group that promotes the development of policy for agroecology (Bellon and Ollivier, 2018). The group was created in 2015, and currently includes 17 countries (Brazil, China, Estonia, France, Ivory Coast, Hungary, Iran, Italy, Ireland, Japan, Madagascar, Mexico, Senegal, Slovenia, Switzerland, The Netherlands, Venezuela). It is an informal and open group, composed of permanent members wishing to support the FAO's work on agroecology, to exchange their national experiences with each other, and to develop scientific partnerships.

Finally, France has also supported new job positions related to agroecology at FAO. Moreover, France is also represented in the Committee on World for Food Security (CFS), an international and intergovernmental platform for stakeholders to work together to ensure food security and nutrition in the world. The Committee reports to the UN General Assembly and to the FAO, and is technically supported and based with the secretariat at the FAO. In the CFS, France chaired until recently the steering committee giving guidance to the HLPE (High Level of Experts) carrying out an expert assessment of "Agroecological approaches and other innovations for sustainable agriculture and food systems that enhance food security and nutrition" ending in early summer 2019 (CFS, 2018; HLPE, 2019).

Overall, it can be stated that France played an important role in the international political arena to support expanding discussion and debates for alternatives to the present agricultural models as well as for upscaling of agroecology at the international level.

## 5 Conclusions

The policy for agroecology started with debates about environmental and natural resource management in France. This translated into a national programme, involving different sectoral programmes, and finally also a law for agroecology in 2014. Sectoral programmes were set up and launched with respect to farming practices and innovation by individual or farmer groups, research incentives for national research programmes were provided, and new agricultural curricula for high schools and higher education institutions were developed. However, the success of the different programmes and policies varies significantly in terms of their impact so far:

1. There has been a quicker and stronger implementation of education and training, and increased research focussing on certain topics.
2. The policy also started a 'movement' in the agricultural sector and brought forward pioneers which stimulated innovation in agroecology such as with the Environmental and Economic Interest Groups.
3. The agroecology policy has facilitated more implementation of agroecological practices, stronger recognition of the importance of biodiversity for agriculture, and more conversion to organic agriculture, but failed to reduce the use of pesticides.
4. French policy on agroecology has clearly demonstrated that it is meeting society's contemporary needs.
5. And finally, the policy development at national level was complemented by lobbying at international level, supporting national implementation.

Overall, some of the sectoral programmes also delivered progress towards sustainable conventional agriculture. The overall agroecology programme also raised awareness about how to farm for the future. It drew attention to the importance of biodiversity and diversification in agriculture, and increased interest in the process quality and re-localisation of food products. Changes and adaptations in education provided a foundation. However, the overall impact might be regarded as limited. But such fundamental change needs more time as is evident from the history of the Green Revolution. Moreover, if the EU agricultural policy with the Farm to Fork strategy and the New Green Deal does not include more elements of agroecology, impact and changes might remain very restricted also in France as the national policies regarding agriculture are framed by EU policy. To scale agroecology up and to further integrate it within the main farming and food systems, much stronger political support and a regulatory framework, both at national and European levels is required. France and its policy for agroecology can be seen as a precursor, at least for now. France will need to pull its weight in the EU and make sure that Farm and Fork and New Green Deal are fully allied with its agroecology policy, otherwise the 10 years of mixed success, but success still, will have been partly in vain.

## Acknowledgments

We are grateful for EU funding for Agroecology Europe in the frame of the LIFE Operating Grant, SGA 2020. We are also grateful to the Fondazione Giangiacomo Feltrinelli, Italy, for funding part of the work of this paper. This paper is based on a former manuscript which was published in the proceedings of the Fondazione Giangiacomo Feltrinelli (Wezel and David, 2019), but which was further developed, enlarged and changed in scope and content within the LIFE project. We highly acknowledge the comments and correction of the three reviewers of this paper which strongly helped to improve the paper.

### REFERENCES

Agence Bio (2019) Les chiffres clefs [online]. Retrieved from <https://www.agencebio.org/wp-content/uploads/2019/06/DP-AGENCE_BIO-4JUIN2019.pdf> [at 30 Nov2020]

Agroecology Europe (2017) Our understanding of agroecology [online]. Retrieved from <http://www.agroecology-europe.org/our-approach/our-understanding-of-agroecology> [at 30 Nov 2020]

AgroMedia (2019) Leclerc fait le choix de la certification HVE pour ses fruits et légumes [online]. Retrieved from <https://www.agro-media.fr/actualite/leclerc-fait-le-choix-de-la-certification-hve-pour-ses-fruits-et-legumes-33117.html> [at 30 Nov 2020]

Ajates Gonzales R, Thomas J, Chang M, (2018) Translating agroecology into policy: the case of France and the United Kingdom. Sustainability 10(8): 2930, doi:10.3390/su10082930

Altieri MA (1989) Agroecology: A new research and development paradigm for world agriculture. Agr Ecosyst Environ 27(1–4):37-46, doi:10.1016/0167-8809(89)90070-4

Altieri MA (1995) Agroecology: the science of sustainable agriculture. 2nd edition. Boulder, CO: Westview Press, 433 p

Arrignon J (1987) Agro-écologie des zones arides et sub-humides. Paris: Editions G-P Masonneuve & Larose et ACCT, 283 p

Bellon S, Ollivier G (2018) Institutionalizing agroecology in France: Social circulation changes the meaning of an idea. Sustainability 10(5):1380, doi:10.3390/su10051380

CFS (2018) Agroecology & Innovations for FSN [online]. Retrieved from <http://www.fao.org/cfs/cfs-hlpe/news-archive/detail/en/c/1103100> [at 28 Feb 2019]

Couturier C, Charru M, Doublet S, Pointereau P (2017) The Afterres 2050 scenario [online]. Association Solagro. Retrieved from <https://afterres2050.solagro.org/2020/02/929/> [at 01 Dec 2020]

Côte FX, Poirier-Magona E, Perret S, Roudier P, Rapidel B, Thirion MC (eds) (2019) La transition agro-écologique des agricultures du Sud. Versailles: Edition Quae, 368 p

Crosskey P (2014) Conversion to agroecology: France's hopes for environmental salvation [online]. ARC2020, 28 p. Retrieved from <https://www.arc2020.eu/wp-content/uploads/2016/01/151228-pesticides-download-rev3-less-compressed.pdf> [at 01 Dec 2020]

De Schutter O (2010) Report submitted by the Special Rapporteur on the right of food, Oliver de Schutter. Human Rights Council, 16th session. Geneva: United Nations, 21 p, A/HRC/16/49. Retrieved from <https://www2.ohchr.org/english/issues/food/docs/a-hrc-16-49.pdf> [at 17 Sept 2020]

ESEC (2012) Bilan du Grenelle de l'environnement : pour un nouvel élan [online]. Retrieved from <https://www.lecese.fr/travaux-publies/bilan-du-grenelle-de-l-environnement-pour-un-nouvel-elan> [at 01 Dec 2020]

EC, European Commission [2013] CAP Reform – an explanation of the main elements [online]. MEMO/13/937, 9 p. Retrieved from <https://ec.europa.eu/commission/presscorner/detail/en/MEMO_13_937> [at 01 Dec 2020]

EC, European Commission (2018) A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment [online]. 107 p. Retrieved from <https://ec.europa.eu/knowledge4policy/publication/sustainable-bioeconomy-europe-strengthening-connection-between-economy-society_en> [at 01 Dec 2020]

EC, European Commission (2020a) Farm to Fork strategy – for a fair, healthy and environmentally-friendly food system [online]. Retrieved from <https://ec.europa.eu/food/farm2fork_en> [at 01 Dec 2020]

EC, European Commission (2020b) EU Biodiversity strategy for 2030 [online]. Retrieved from <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en> [at 01 Dec 2020]

Eurostat (2018) Pesticide sales, percentage change 2016 compared with 2011 for 16 EU member states [online]. Retrieved from <https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Pesticide_sales,_percentage_change_2016_compared_with_2011_for_16_EU_Member_States_.png&oldid=398428> [at 01 Dec 2020]

Eurostat [2019] Agri-environmental indicator – consumption of pesticides [online]. Retrieved from <https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides> [at 01 Dec 2020]

Francis C, Lieblein G, Gliessman S, Breland TA, Creamer N, Harwood R, Salomonsson L, Helenius J, Rickerl D, Salvador R, et al. (2003) Agroecology: the ecology of food systems. J Sustain Agric 22(3):99–118, doi:10.1300/J064v22n03_10

Fritz M, Schiefer G (2008) Food chain management for sustainable food system development: a European research agenda. Agribusiness 24(4): 440–452, doi:10.1002/agr.20172

Gliessman SR (2007) Agroecology: the ecology of sustainable food systems. New York: CRC Press, 384 p

Gliessman SR (2018) Defining agroecology. Agroecol Sustain Food Syst 42(6):-599–600, doi:10.1080/21683565.2018.1432329

Gramond F (2015) Perception de l'agroécologie par les agriculteurs [online]. Retrieved from <https://www.bva-group.com/sondages/perception-de-lagro-ecologie-par-les-agriculteurs-francais/> [at 15 Dec 2020]

Gramond F (2016) Perception de l'agro-écologie par les agriculteurs français. Evolution depuis un an [online]. Retrieved from <https://agriculture.gouv.fr/sites/minagri/files/presentation_bva_agro-ecologie_15-16_v3_revbh.pdf> [at 15 May 2019]

Guillou M, Guyomard H, Huygue C, Peyraud JL (2013) Le projet agro-écologique: vers des agricultures doublement performantes pour concilier compétitivité et respect de l'environnement. Propositions pour le Ministre [online]. 163 p. Retrieved from <https://agriculture.gouv.fr/sites/minagri/files/documents//rapport_marion_guillou_cle05bdf5.pdf> [at 15 Dec 2020]

Guillou M, Riba G, Houllier F, Eddi M, Leverve X, Guyomard H, Soussana JF, Chemineau P (2010) INRA's scientific priorities for 2010–2020: targeted research [online]. 19 p. Retrieved from <https://hal.inrae.fr/hal-02819525/document> [at 01 Dec 2020]

Guilloux JM, Denoux P (2014) L'intelligence est dans le pré. Penser la ruralité du XXIème siècle. Paris: Edition François Bourin, 340 p

Hermon C (2015) L'agroécologie en droit: état et perspectives [online]. Revue juridique de l'environnement 40(3): 407–422. Retrieved from <https://www.cairn.info/revue-revue-juridique-de-l-environnement-2015-3-page-407.htm> [at 01 Dec 2020]

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]

IAASTD (2009) Global report: International Assessment of Agricultural knowledge, science and technology for development. Washington: Island Press, 592 p, Agriculture at a crossroads. Retrieved from <https://www.weltagrarbericht.de/fileadmin/files/weltagrarbericht/IAASTDBerichte/GlobalReport.pdf> [at 10 Dec 2020]

INRA (2010) Document d'orientation INRA 2010–2020: une science pour l'impact. 56 p. Retrieved from <https://hal.inrae.fr/hal-02823708/document> [at 10 Dec 2020]

INRA, CIRAD (2016) Agro-ecology. Strategic research at INRA and CIRAD [online]. 8 p. Retrieved from <https://www.cirad.fr/en/news/all-news-items/articles/2016/institutionnel/agro-ecology-cirad-and-inra-showcase-their-joint-position> [at 10 Dec 2020]

Lamichhane JR, Messéan A, Ricci P (2019) Research and innovation priorities as defined by the Ecophyto plan to address current crop protection transformation challenges in France. Adv Agron 154:81–152, doi:10.1016/bs.agron.2018.11.003

Légifrance (2017) Code rural et de la pêche maritime. Livre Préliminaire: Objectifs de la politique en faveur de l'agriculture, de l'alimentation et de la pêche maritime [online]. Retrieved from <http://www.legifrance.gouv.fr/affichCode.do?cidTexte=LEGITEXT000006071367> [at 15 Dec 2017]

Légifrance (2018) LOI no 2018-938 du 30 octobre 2018 pour l'équilibre des relations commerciales dans le secteur agricole et alimentaire et une alimentation saine, durable et accessible à tous [online]. Retrieved from <https://www.legifrance.gouv.fr/affichLoiPreparation.do?idDocument=JORFDOLE000036562265&type=general&typeLoi=proj&legislature=15> [at 01 Dec 2020]

Loconto A, Fouilleux E (2019) Defining agroecology: Exploring the circulation of knowledge in FAO's global dialogue. IJSAF 25(2):116–137. Retrieved from <https://d0f777f0-44f0-4115-a90d-3efac4187b3c> [at 10 Dec 2020]

Méndez VE, Bacon CM, Cohen R (2013) Agroecology as a transdisciplinary, participatory, and action-oriented approach. Agroecol Sustain Food Syst 37(1):3–18, doi:10.1080/10440046.2012.736926

Migliorini P, Wezel A (2018) Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review. Agron Sustain Dev 37:63, doi:10.1007/s13593-017-0472-4

Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt (2016a) Le projet agro-écologique en France [online]. Retrieved from <http://agriculture.gouv.fr/agriculture-et-foret/projet-agro-ecologique> [at 15 Jan 2019]

Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt (2016b) Le projet agro-écologique en 12 clés [online]. Retrieved from <https://agriculture.gouv.fr/le-projet-agro-ecologique-en-12-cles> [at 01 Dec 2020]

Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt (2016c) Bio et haute valeur environnementale : deux modes de valorisation complémentaires [online]. Retrieved from <https://agriculture.gouv.fr/bio-et-haute-valeur-environnementale-deux-modes-de-valorisation-complementaires> [at 01 Dec 2020]

Ministère de l'Agriculture et de l'Alimentation (2018) European and international strategy 2018–2022 [online]. Retrieved from <https://agriculture.gouv.fr/la-strategie-europe-et-international-2018-2022-du-ministere-de-lagriculture-et-de-lalimentation/en> [at 1 Dec 2020]

Ministère de l'Agriculture et de l'Alimentation (2019a) Les fermes Dephy: partout en France, des systèmes de production performants et économes en pesticides [online]. Retrieved from <https://agriculture.gouv.fr/les-fermes-dephy-partout-en-france-des-systemes-de-production-performants-et-economes-en-0> [at 1 May 2019]

Ministère de l'Agriculture et de l'Alimentation (2019b) Alim'agri [online]. Retrieved from <https://agriculture.gouv.fr/mots-cles/alimagri> [at 15 Febr 2019]

Ministère de l'Agriculture et de l'Alimentation (2019c) Les groupements d'intérêt économique et environnemental (GIEE) [online]. Retrieved from <http://agriculture.gouv.fr/les-groupements-dinteret-economique-et-environnemental-giee> [at 15 March 2020]

Ministère de l'Agriculture et de l'Alimentation (2019d) Infographics – Law to promote balanced commercial relationships in the agricultural and food sector and healthy, sustainable food [online]. Retrieved from <https://agriculture.gouv.fr/infographics-law-promote-balanced-commercial-relationships-agricultural-and-food-sector-and-healthy> [at 01 Dec 2020]

Muller A, Schader C, Scialabba NEH, Brüggemann J, Isensee A, Erb KH, Smith P, Klocke P, Leiber F, Stolze M, Niggli U (2017) Strategies for feeding the world more sustainably with organic agriculture. Nat Commun 8:1290, doi:10.1038/s41467-017-01410-w

National Farmers Union (2015) Agroecology in Canada: Food sovereignty in action [online]. Retrieved from <https://www.nfu.ca/wp-content/uploads/2018/05/Agroecology-booklet-eng-final.pdf> [at 15 May 2019]

Niggli U (2015) Incorporating agroecology into organic research – an ongoing challenge. Sustain Agric Res 4(3):149–157, doi:10.5539/sar.v4n3p149

Norder LA, Lamine C, Bellon S, Brandenburg A (2016) Agroecology: polysemy, pluralism and controversies. Ambient Soc 19(3):1–20, doi:10.1590/1809-4422ASOC129711V1932016

Paillard S, Treyer S, Dorin B (eds) (2010) Agrimonde: scénarios et défis pour nourrir le monde en 2050. Versailles: Editions Quae, 295 p

Poux X, Aubert PM (2018) An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the ten years for agroecology (TYFA) modelling exercise [online]. 74 p. Retrieved from <https://www.iddri.org/en/publications-and-events/study/agroecological-europe-2050-multifunctional-agriculture-healthy-eating> [at 10 Dec 2020]

UVAE, Université Virtuelle d'Agroécologie (2019) Ressources pour la formation en ligne à l'agroécologie [online]. Retrieved from <https://www6.inra.fr/uvae/> [at 01 Dec 2020]

Wezel A, Bellon S, Doré T, Francis C, Vallod D, 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

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

Wezel A, David C (2012) Agroecology and the food system. In: Lichtfouse E (ed) Agroecology and strategies for climate change. Dordrecht: Springer, 17–33, doi:10.1007/978-94-007-1905-7

Wezel A, David C (2019) French policy for agroecology – development, implementation, and lessons learned. In: Chiappero E (Rules of Utopia. Policies to drive us out of the crisis. Milano: Fondazione Giangiacomo Feltrinelli, 126–150, Quaderni/30

Wezel A, David C, Ferrer A, Letort A, Féret S, Peigné J, Vian JV, Celette F (2014b) Agroecological practices supporting provision of goods and services in agriculture: Examples from France and Europe. Lyon: ISARA 67 p

Wezel A, Fleury P, David C, Mundler P (2015) The food system approach in agroecology supported by natural and social sciences: topics, concepts, applications. In: Benkeblia N (ed) Agroecology, ecosystems, and sustainability. Boca Raton, FL: CRC Press, 181–199, doi:10.1201/b17775

Wezel A, Goette J, Lagneaux E, Passuello G, Reisman E, Rodier C, Turpin G (2018) Agroecology in Europe: Research, education, collective action networks, and alternative food systems. Sustainability 10(4):1214, doi:10.3390/su10041214

Wezel A, Soldat V (2009) A quantitative and qualitative historical analysis of the scientific discipline agroecology. Int J Agr Sustain 7(1):3–18, doi:10.3763/ijas.2009.0400

POSITION PAPER

# Agroecology as a means to transform the food system

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Received: June 25, 2020
Revised: September 4, 2020
Accepted: October 9, 2020


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KEYWORDS **food security, nutrition, resilience, equity, sustainable food systems**

## 1 Why does the food system need transformation?

The current global food system(s) has many negative environmental, nutritional, economic and socio-political impacts. Environmental impacts include high levels of greenhouse gas emissions (IPCC, 2019), water pollution (Evans et al., 2019), land degradation, biodiversity loss and the decline of other ecosystem services (IPBES, 2019), which have led some scientists to suggest the food system is exceeding 'planetary boundaries' (Campbell et al., 2017). While there is more than enough food produced to feed global populations, over 800 million people experience chronic food insecurity and suffer from malnutrition, with more than $10^9$ people suffering health problems associated with overconsumption of food high in fat, salt and sugar (FAO et al., 2019; Willet et al., 2019). Although the majority of the world's food, and in particular nutritious food types, is still produced by small to mid-sized farmers, fishers and livestock keepers (Herrero et al., 2017), it is increasingly difficult for small and medium-sized farming households and food enterprises to survive, making rural livelihoods often fragile and precarious (HLPE, 2013). Concerns have also been raised about the democratic governance and equity of the food system, with the profits and control accruing increasingly to a very concentrated few large companies, on both the input and supply side (IPES-Food, 2016). The covid-19 pandemic underscored weaknesses in the food system, increasing risks of supply shortages in some supply chains, revealing the vulnerability of many households to food insecurity, the lack of adequate social safety nets, and the linkages between environmental and human health (Altieri and Nicholls, 2020; Blay Palmer et al., 2020). Numerous scientific studies and reviews have called for the transformation of the food system, to ensure that it is kept within environmental limits while addressing these health, food security, social and political concerns (IPES-Food, 2016; Mbow et al., 2019; Springmann et al., 2018; Willet et al., 2019). Agroecology is one potential overarching approach to transform the food system and to address these interacting and overlapping negative impacts, which includes a focus on power inequities (Blay-Palmer et al., 2020; HLPE, 2019; Mbow et al., 2019).

## 2 How can agroecology help to transform the food system?

Agroecology is a holistic approach to food production, which uses ecological methods while also addressing the health, social and economic dimensions of the food system (HLPE, 2019). Considered a science, practice and social movement, agroecology operates at the field, farm and food system levels (Wezel et al., 2014). Agroecological practices include increasing biodiversity, recycling organic material, minimising toxic inputs such as pesticides, and having integrated

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crop-livestock systems. Some scholars differentiate between scientific agroecology which focuses on the ecological processes to harness in agricultural production, and political agroecology that considers the social, political and economic dimensions of food production in system transformation (Méndez et al., 2013). Political agroecology proponents argue that to transform the food system requires efforts that address its inequities and tackle power dynamics at multiple scales (Anderson et al., 2020; González de Molina et al., 2019). Principles of agroecology which do so include addressing social (in)justice and equity, (re)building direct linkages between producers and consumers, co-production of scientific knowledge, and fostering greater democratic governance of the food system (Dumont et al., 2016; FAO, 2018; HLPE, 2019). Agroecological practices beyond the farm gate comprise initiatives that 1) address gender inequity; 2) use horizontal educational methods such as farmer-to-farmer networks and participatory guarantee systems that link producers to consumers to ensure transparency and equity in local markets (Dumont et al., 2016; Loconto et al., 2018; HLPE, 2019). Transforming governance processes, so that power inequities between consumers, producers, governments and multinational companies are addressed at multiple scales, is considered a key dimension of agroecological transitions (Anderson et al., 2020). Political agroecological initiatives aim at establishing mechanisms for small-scale farmers to have input into policies that influence their production systems, such as increased tenure for land rights or access, greater control over seeds, subsidies for diversified production and addressing consumer needs, e.g. by subsidizing locally produced nutritious foods (Anderson et al., 2020).

## 3 Environmental, health, social, economic and political dimensions of food system: Evidence for agroecology's impact

### 3.1 Environmental impacts

There is increasing evidence of the positive environmental impacts from the use of agroecology. A systematic review found robust evidence that agroecological practices are effective for climate change adaptation, using key indicators such as soil organic carbon, soil microbial activity, crop yield stability, biodiversity conservation, and natural plant protection (Muller et al., under review). Landscape complexity is another important feature, through the use of hedgerows, intercropping, and integration of animals, forests, wetlands and other landscapes, which allows for multipurpose benefits, including biodiversity conservation and climate change adaptation (Kremen and Merenlender, 2018; Kremen and Miles, 2012). The integration of livestock, trees and cropping systems allows for food production, biodiversity conservation and carbon sequestration, for example with free-range poultry and olive orchards (Paolotti et al., 2016). Generally, agroforestry systems could be considered as part of an agroecological approch, and provide sources of food, livelihoods and ecosystem services including carbon sequestration (Lasco et al., 2014; Mbow et al., 2014).

### 3.2 Food security, nutrition and health

Increasing biodiversity in farming systems, a key practice in agroecology, has been significantly and positively associated with many changes. These include improved dietary diversity, food security and nutrition for small-scale food producers and rural communities, although with context-specific impacts (Bellon et al., 2016; Bezner Kerr et al., 2019a; Bharucha et al., 2020; Jones, 2017; Luna-González and Sørensen, 2018; Pellegrini and Tasciotti, 2014; Powell et al., 2015). A recent study of Zero Budget Natural Farming (ZBNF) in India, a grassroots movement promoting agroecological practices, found that while this approach is likely to reduce soil degradation and improve yields for low-input farmers, those who rely on high input levels are likely to experience yield penalties due to nitrogen limitations (Smith et al., 2020). Other studies looking at the social and ecological impacts of the ZBNF approach in India have found significant increases in income, food security and farmer autonomy (Bharucha et al., 2020; Khadse et al., 2018). Health impacts from agroecological approaches, for which there is less evidence to date, are reduced exposure to toxic inputs such as pesticides and improved mental health outcomes. In India, farmers participating in the ZBNF initiative have reported improved health and household income resulting from reduced purchased inputs such as pesticides (Khadse et al., 2018). A case-control longitudinal study of 548 households participating in an agroecology and nutrition project in Tanzania found significant improvements in women's mental health, linked to improved food security (Cetrone et al., 2020). The emphasis of agroecology on the co-creation of knowledge, experimentation and greater linkages between producers and consumers, can also provide more opportunities for meaningful, decent work for smallholder farmers with potential impacts on well-being (Bezner Kerr et al., 2019b; Timmerman and Félix, 2015; Deaconu et al., 2019).

### 3.3 Food production productivity

Globally, there is concern that agroecology cannot provide adequate food for growing urban populations. One modelling study by Muller et al. (2017) considered the potential to convert to organic production under different climate change scenarios and with other food system changes including addressing food waste and changing food consumption patterns. They found that a complete conversion to organic production will use more land but have environmental benefits associated with reduced pesticide use, nitrogen pollution and greenhouse gas emissions, although there would need to be adjustments in consumption practices and food waste crucial to ensure sustainable food systems. At a regional scale, one study in Europe modelled a transition to agroecological methods over 10 years, and estimated that while food requirements would be met, there would be a decline in food production by 35 %, while improving biodiversity, natural resource conservation and reduction of greenhouse gas emissions by 45 % (Poux and Aubert, 2018). Other meta-reviews of the global potential for organic and agroecological food production methods have found changes in yield ranging from 27 % declines to 61 % increases (Barbieri et al., 2019; D'Annolfo et al., 2017; Reganold and Wachter, 2016; Ponisio et al., 2015). These studies have ranged in terms of what crops, rotations, intercrops, consumption patterns, food waste and other assumptions are built into the models, with most models relying on high income country data sets, and not differentiating between organic and agroecological production. Since organic production includes large-scale, industrial style monocrop production, such models do not fully assess the potential of a diversified, agroecological approach. Given the limited investment in agroecological research (DeLonge et al., 2016; Miles et al., 2017; Pimbert and Moeller, 2018), these global and regional models need further elaboration on the impacts of agroecological production.

### 3.4 Labour, livelihoods and employment

There is limited research to date on the labour implications of agroecological practices, or on the livelihood- and employment-related implications. While some scholars purport that mechanised farms are beneficial because of the labour-intensity of agroecological practices, it is neither known to what extent this helps, nor what the implications of labour-intensified farming practices will be (HLPE, 2019). There are often tradeoffs between capital costs of mechanisation, associated debt load, reduced autonomy and labour. In-depth interviews in Malawi with over 100 farmers who used agroecological practices found that many small-scale farmers did not consider agroecological practices to be more labour intensive, but instead re-directed their labour to their farms, instead of off-farm labour during times of food shortages. Intercropping could reduce labour due to reduced weeding requirements. Other farmers did find crop diversification and compost production more labour intensive, and reported tradeoffs with child care and leisure (Bezner Kerr et al., 2019b).

Overall impacts that agroecological approaches have on income and livelihoods is also a research gap. A number of studies have reported that agroecology can increase incomes by diversifying the crops and animals that can be sold, reducing purchased inputs and associated debt loads (Padulosi et al., 2015; Bharucha et al., 2020). Our research in Malawi with over 1000 households found a significant increase in both food security and income for those households using agroecological practices (Kanmennang et al., 2017). Some of the increased income arises from reductions in purchased inputs, but we also found evidence of increased social capital arising from farmer networks (Kansanga et al., 2020). In regions where labour is more available than capital, particularly for small-scale farmers, such as south Asia or sub-Saharan Africa, labour-saving practices may not be desirable. The increased use of labour-saving technologies such as herbicides or mechanisation can actually reduce employment opportunities for low income rural workers and reduce the viability of farming for small-scale farms. In contrast, agroecological principles, which emphasize localized economies with shorter value chains, can support increased local food businesses (Loconto et al., 2018). Regional or territorial approaches can be important to support diversified livelihoods and local economies. One global meta-review found that diversified farming systems increased employment in 44 countries (Garibaldi and Pérez-Méndez, 2019). Further research on agroecology's impact on working conditions, employment and livelihoods is needed.

## 4 Political dimensions of agroecology

A number of studies examine the political dimensions of agroecology at a national or regional scale. The French government implemented a law to transition to agroecology, which included initiatives to support it, bringing together farmers, academics, non-governmental organisations and educational organisations. The government effort comprised over 10 million Euros and supported 9000 farmers, along with other stakeholders, working on agroecological initiatives, and, although, limited to date, raised awareness about alternative approaches to intensified production (Bellon and Ollivier, 2018). In Brazil, social movements and civil society mobilisation supported a widespread effort to address family farming, which included agroecological initiatives within particular public policies, despite agricultural intensification as a dominant paradigm (Petersen and Silveira, 2017). A 'National Policy for Agroecology and Organic Production' was established in 2013. National programmes supported different agroecology networks and initiatives, including community seed banks, agroecological fairs, and support to agroecological farmers to sell to the national school meals programmes (Petersen and Silveira, 2017; Valencia et al., 2019; Wittman and Blesh, 2017). The Zero Budget Natural Farming network in India has mobilised hundreds of thousands of farmers to use organic farming methods, which has reduced their input dependency (Khadse et al., 2018). The state of Andra Pradesh in India has supported this approach through government extension and funding. Political mobilisation around natural farming methods as a means to reduce farmer indebtedness, a major issue in India, has been one of the features of success in this context (Khadse et al., 2018).

## 5 What are some examples of the integrated impacts of agroecology?

In smallholder farming communities in Malawi, long term research on those using agroecological methods showed evidence of improved food security, nutrition, sustainable land management and gender relations through innovative educational strategies and agroecological approaches (Bezner Kerr et al., 2019a; Bezner Kerr et al., 2019b; Kangmennaang et al., 2017; Kansanga et al., 2020). Participatory, community-based methods were key, including the use of theatre, small group discussions, on-farm experiments and farmer-to-farmer teaching and efforts to address household gender inequities in workload and decision-making (Bezner Kerr et al., 2019c; Nyantakyi-Frimpong et al., 2017). Farmers tested a range of agroecological practices including legume intercrops, compost, agroforestry and crop diversification, which had positive impacts on yield stability, reduced fertiliser inputs and increased soil cover (Snapp et al., 2010; Bezner Kerr et al., 2007; Bezner Kerr et al., 2019a). There was evidence of gender power inequities being addressed, with women having more of a say in farming, while men reported greater involvement in childcare and household work (Bezner Kerr et al., 2019b). Communities also mobilised to share seeds, knowledge with other villages, helping to build social capital (Bezner Kerr et al., 2018; Kansanga et al., 2020).

At a regional scale, in southeast France, the Drôme Valley has a strong network of cooperatives, organic farmers and organic supply chains, supporting livestock rearing, wine, cereal, fruit and lavender production (INSEE, 2011). A collaboration between the regional government, cooperatives, farmers and local businesses supported knowledge-exchange groups for organic production, a large-scale food hub and vegetable processing factory, alongside public procurement of organic foods for school canteens and daycare centres. Diversified organic production and local consumption has increased significantly alongside local business opportunities in the valley (Wezel and David 2012; Bui, 2015; IPES-Food, 2018).

In Brazil, there is evidence that social mobilisation led to increased land access and public procurement policies such as the 'National School Feeding Programme'. It also supported farmers who have diversified farm products, and provides a premium for certified organic and agroecological production. It also increases agrobiodiversity on-farm, and reduces input intensity, particularly for larger farms (Valencia et al., 2019). Farmers also invested more in soil health with increased application of manure and compost (Blesh and Wittman, 2015). Farmers reported that they shifted from low diversity, high-input farming systems to diverse, low input systems, in part because of the guaranteed, stable source of income from the national school feeding programme, alongside the support from non-governmental organisations and farmer organisations (Guerra et al., 2017; Valencia et al., 2019). The 'Bolsa Familia' programme, part of the 'Zero Hunger' strategy, provided cash stipends for low income households that also helped boost local economies, and allowed many farm labourers to become independent farmers. Small scale producers were linked with schools for the supply of fresh nutritious meals. School lunch programmes reduced in cost while improving in food quality: the offering of fruits and vegetables in schools increased from 28 % and 57 % in 2004 to 62 % and 80 % in 2006, respectively (Wittman and Blesh, 2017).

## 6 Conclusion

Many scientific and policy reports have noted the need to transform food systems to ensure the long-term sustainability of our planet and communities. Most policy efforts, however, tend to focus on technical, agronomic field-level initiatives or changes in individual consumer behaviours (e.g. Willett et al., 2019; Springmann et al., 2018). Such efforts are likely to replicate the same forces that benefit from the current food system. Agroecology is a transformative approach that brings together environmental, social and political aims. One important aspect of agroecology is a focus on power inequities through addressing social, economic and political dimensions of food production (HLPE, 2019). While there is considerable evidence of its potential, there are also major barriers to using agroecological approaches, since this approach tackles power inequities at multiple scales, such as the concentrated power of input suppliers and retailers in the food system, and gender inequities, through increasing both producer and consumer agency (HLPE, 2019). Effective transformation will require concerted attention to tackling such power dynamics, alongside the complex, context specific questions of effective ecological methods of food production (Anderson et al., 2020). Although further investments in the analysis of impacts of agroecological approaches on labour, employment, global and regional food production and health outcomes are needed, there is considerable evidence to date which supports agroecology's potential to meet social, economic, health and environmental priorities in society.

### REFERENCES


Altieri MA, Nicholls CI (2020) Agroecology and the emergence of a post COVID-19 agriculture. Agric Hum Values 37:525–526, doi:10.1007/s10460-020-10043-7

Anderson CR, Bruil J, Chappell MJ, Kiss C, Pimbert MP (2019) From transition to domains of transformation: Getting to sustainable and just food systems through agroecology. Sustainability 11(19):5272, doi:10.3390/su11195272

Barbieri P, Pellerin S, Seufert V, Nesme T (2019) Changes in crop rotations would impact food production in an organically farmed world. Nat Sustain 2(5):378–385, doi:10.1038/s41893-019-0259-5

Bellon MR, Ntandou-Bouzitou GD, Caracciolo F (2016) On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in southern Benin, West Africa. PLoS ONE 11(9):e0162535, doi:10.1371/journal.pone.0162535

Bellon S, Ollivier G (2018) Institutionalizing agroecology in France: Social circulation changes the meaning of an idea. Sustainability 10(5):1380, doi:10.3390/su10051380

Bezner Kerr R, Hickey C, Lupafya E, Dakishoni L (2019b) Repairing rifts or reproducing inequalities? Agroecology, food sovereignty, and gender justice in Malawi. J Peasant Stud 46(7):1499–1518, doi:10.1080/03066150.208.1547897

Bezner Kerr R, Kangmennaang J, Dakishoni L, Nyantakyi-Frimpong H, Lupafya E, Shumba L, Msachi R, Odei Boateng G, Snapp SS, Chitaya A, et al. (2019a) Participatory agroecological research on climate change adaptation improves smallholder farmer household food security and dietary diversity in Malawi. Agric Ecosyst Environ 279:109–121, doi:10.1016/j.agee.2019.04.004

Bezner Kerr R, Nyantakyi-Frimpong H, Dakishoni L, Lupafya E, Shumba L, Luginaah I, Snapp SS (2018) Knowledge politics in participatory climate change adaptation research on agroecology in Malawi. Renew Agric Food Syst 33(3):238–251, doi.10.1017/S1742170518000017

Bezner Kerr R, Snapp SS, Chirwa M, Shumba L, Msachi R (2007) Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. Exp Agric 43(4):437–453, doi:10.1017/S0014479707005339

Bezner Kerr R, Young SL, Young C, Santoso MV, Magalasi M, Entz M, Lupafya E, Dakishoni L, Morrone V, Wolfe D, Snapp SS (2019c) Farming for change: Developing a participatory curriculum on agroecology, nutrition, climate change and social equity in Malawi and Tanzania. Agric Hum Values 36(3):549-566, doi:10.1007/s10460-018-09906-x

Bharucha ZP, Mitjans SB, Pretty J (2020) Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. Int J Agric Sustain 18(1):1–20, doi:10.1080/14735903.2019.1694465

Blay-Palmer A, Carey R, Valette E, Sanderson MR (2020) Post COVID 19 and food pathways to sustainable transformation. Agric Hum Values 37:-517–519, doi:10.1007/s10460-020-10051-7

Blesh J, Wittman H (2015) "Brasilience": Assessing resilience on land reform settlement farms in the Brazilian Cerrado. Hum Ecol 43:531–546, doi:10.1007/s10745-015-9770-0

Bui S (2015) Pour une approche territoriale des transitions écologiques. Analyse de la transition vers l'agroécologie dans la Biovallée (1970–2015). Paris: AgroParisTech, 502 p, Thesis Doctorat Paris Tech

Campbell BM, Beare DJ, Bennett EM, Hall-Spencer JM, Ingram JSI, Jaramillo F, Ortiz R, Ramankutty N, Sayer JA, Shindell D (2017) Agriculture production as a major driver of the Earth system exceeding planetary boundaries. Ecol Soc 22(4):8, doi:10.5751/ES-09595-220408

Cetrone H, Santoso M, Petito L, Bezner Kerr R, Blacker L, Kassim N, Mtinda E, Martin H, Young S (2020) A participatory agroecological intervention reduces women's risk of probable depression through improvements in food security in Singida, Tanzania. Curr Dev Nutr 4 (Issue Supplement_2):819, doi:10.1093/cdn/nzaa053_024

D'Annolfo R, Gemmill-Herren B, Graeub B, Garibaldi LA (2017) A review of social and economic performance of agroecology. Int J Agric Sustain 15(6):632–644, doi:10.1080/14735903.2017.1398123

Deaconu A, Mercille G, Batal M (2019) The agroecological farmer's pathways from agriculture to nutrition: A practice-based case from Ecuador's highlands. Ecol Food Nutr 58(2):142–165, doi:10.1080/03670244.2019.1570179

DeLonge MS, Miles A, Carlisle L (2016) Investing in the transition to sustainable agriculture. Environ Sci Policy 55(1): 266–273, doi:10.1016/j.envsci.2015.09.013

Dumont AM, Vanloqueren G, Stassart PM, Baret PV (2016) Clarifying the socioeconomic dimensions of agroecology: between principles and practices. Agroecol Sustain Food 40(1):24–47, doi:10.1080/21683565.2015.1089967

Evans AEV, Mateo-Sagasta J, Qadir M, Boelee E, Ippolito A (2019) Agricultural water pollution: key knowledge gaps and research needs. Curr Opin Environ Sustain 36:20–27, doi:10.1016/j.cosust.2018.10.003

FAO (2018) The 10 elements of agroecology: Guiding the transition to sustainable food and agricultural systems [online]. Retrieved from <http://www.fao.org/3/i9037en/i9037en.pdf> [at 4 Sept 2020]

FAO, IFAD, UNICEF, WFP and WHO (2019) The state of food security and nutrition in the world: Safeguarding against economic slowdowns and downturns [online]. Rome:FAO, 239 p. Retrieved from <https://www.wfp.org/publications/2019-state-food-security-and-nutrition-world-sofi-safeguarding-against-economic> [at 22 Dec 2020]

Garibaldi LA, Pérez-Méndez N (2019) Positive outcomes between crop diversity and agricultural employment worldwide. Ecol Econ 164:106358, doi:10.1016/j.ecolecon.2019.106358

González de Molina M, Petersen PF, Garrido Peña F, Caporal FR (2019) Political agroecology: Advancing the transition to sustainable food systems. Boca Raton: CRC Press, 217 p, doi:10.1201/9780429428821

Herrero M, Thornton PK, Power B, Bogard JR, Remans R, Fritz S, Gerber JS, Nelson G, See L, Waha K, et al. (2017) Farming and the geography of nutrient production for human use: a transdisciplinary analysis. Lancet Planet Health 1(1):e33–e42, doi:10.1016/S2542-5196(17)30007-4

HLPE (2013) Investing in smallholder agriculture for food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security [online]. Rome:HLPE c/o FAO, 112p. Retrieved from <http://www.fao.org/3/a-i2953e.pdf> [at 4 Sept 2020]

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security [online]. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 10 Sept 2020]

INSEE (2011) Synthèse de territoire Vallée de la Drôme-Diois [online]. Retrieved from <https://www.insee.fr/fr/statistiques/fichier/1292672/SL_Vallee_Drome_Diois.pdf> [at 4 Sept 2020]

IPBES (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the [online]. Retrieved from <https://ipbes.net/sites/default/files/2020-02/ipbes_global_assessment_report_summary_for_policymakers_en.pdf> [at 4 Sept 2020]

IPCC (2019) Climate Change and Land. An IPCC Special Report [online]. Retrieved from <https://www.ipcc.ch/srccl/> [at 22 Dec 2020]

IPES-Food (2016) From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems [online]. Retrieved from <http://www.ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf> [at 7 Dec 2020]

IPES-Food (2018) Breaking away from industrial food and farming systems: Seven case studies of agroecological transition [online]. Retrieved from <http://www.ipes-food.org/_img/upload/files/CS2_web.pdf> [at 4 Sept 2020]

Jones AD (2017) Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. Nutr Rev 75(10):769–782, doi:10.1093/nutrit/nux040

Kangmennaang J, Bezner Kerr R, Lupafya E, Dakishoni L, Katundu M, Luginaah I (2017) Impact of a participatory agroecological development project on household wealth and food security in Malawi. Food Secur 9:-561–576, doi:10.1007/s12571-017-0669-z

Kansanga MM, Luginaah I, Bezner Kerr R, Lupafya E, Dakishoni L (2020) Beyond ecological synergies: examining the impact of participatory agroecology on social capital in smallholder farming communities. Int J Sust Dev World 27(1)1–14, doi:10.1080/13504509.2019.1655811

Khadse A, Rosset PM, Morales H, Ferguson BG (2018) Taking agroecology to scale: the Zero Budget Natural Farming peasant movement in Karnataka, India. J Peasant Stud 45(1):192–219, doi:10.1080/03066150.2016.1276450

Kremen C, Merenlender AM (2018) Landscapes that work for biodiversity and people. Science 362(6412):eaau6020, doi:10.1126/science.aau6020

Kremen C, Miles A (2012) Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecol Soc 17(4):40, doi:10.5751/ES-05035-170440

Lasco RD, Delfino RJP, Espaldon MLO (2014) Agroforestry systems: helping smallholders adapt to climate risks while mitigating climate change. WIREs Clim Change 5(6):825–833, doi:10.1002/wcc.301

Loconto A, Jimenez A, Vandecandelaere E (2018) Constructing markets for agroecology: An analysis of diverse options for marketing products from agroecology [online]. Rome: FAO/INRA, 198 p. Retrieved from <http://www.fao.org/3/I8605EN/i8605en.pdf> [at 7 Dec 2020]

Luna-González DV, Sørensen M (2018) Higher agrobiodiversity is associated with improved dietary diversity, but not child anthropometric status, of Mayan Achí people of Guatemala. Public Health Nutr 21(11): 2128–2141, doi:10.1017/S1368980018000617

Mbow C, Rosenzweig C, Barioni LG, Benton TG, Herrero M, Krishnapillai M, Liwenga E, Pradhan P, Rivera-Ferre MG, Sapkota T, et al. (2019) Food Security. In: Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner H-O, Roberts DC, Zhai P, SladeR, Connors S, van Diemen R, et al. (eds) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Chapter 5, 437–550. Retrieved from <https://www.ipcc.ch/site/assets/uploads/2019/11/08_Chapter-5.pdf> [at 10 Dec 2020]

Mbow C, Smith P, Skole D, Duguma L, Bustamante M (2014) Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Curr Opin Environ Sustain 6:8–14, doi:10.1016/j.cosust.2013.09.002

Méndez VE, Bacon CM, Cohen R (2013) Agroecology as a transdisciplinary, participatory, and action-oriented approach. Agroecol Sustain Food 37(1):3–18, doi:10.1080/10440046.2012.736926

Miles A, DeLonge MS, Carlisle L (2017) Triggering a positive research and policy feedback cycle to support a transition to agroecology and sustainable food systems. Agroecol Sustain Food 41(7): 855–879, doi:10.1080/21683565.2017.1331179

Muller A, Leippert F, Darmaun M, Mpheshea M, Nesper M, Herren M, Bellon S, Bezner Kerr R, DePorras M, Grovermann C, Smith P, Stöckli S, Bernoux M (under review) Agroecology's potential to adapt to climate change. Submitted to PNAS USA

Muller A, Schader C, El-Hage Scialabba N, Brüggemann J, Isensee A, Erb K-H, Smith P, Klocke P, Leiber F, Stolze M, Niggli U (2017) Strategies for feeding the world more sustainably with organic agriculture. Nat Commun 8(1):-1290, doi:10.1038/s41467-017-01410-w

Nyantakyi-Frimpong H, Hickey C, Lupafya E, Dakishoni L, Bezner Kerr R, Nyirenda B, Nkhonya Z, Katundu M, Gondwe G (2017) A farmer-to-farmer agroecological approach to addressing food security in Malawi [online]. In: People's knowledge editorial collective (eds) Everyday experts: How people's knowledge can transform the food system. Chapter 8. Coventry: Coventry University, 119–134. Retrieved from <www.coventry.ac.uk/everyday-experts> [at 10 Dec 2020]

Padulosi S, Mal B, King OI, Gotor E (2015) Minor millets as a central element for sustainably enhanced incomes, empowerment, and nutrition in rural India. Sustainability 7(7):8904–8933, doi:10.3390/su7078904

Paolotti L, Boggia A, Castellini C, Rochi L, Rosati A (2016) Combining livestock and tree crops to improve sustainability in agriculture: a case study using the Life Cycle Assessment (LCA) approach. J Clean Prod 131:351–363, doi:10.1016/j.jclepro.2016.05.024

Pellegrini L, Tasciotti L (2014) Crop diversification, dietary diversity and agricultural income: empirical evidence from eight developing countries. Can J Dev Stud 35(2):211–227, doi:10.1080/02255189.2014.898580

Petersen PF, Silveira LM (2017) Agroecology, public policies and labor-driven intensification: Alternative development trajectories in the Brazilian semi-arid region. Sustainability 9(4):535, doi:10.3390/su9040535

Pimbert M, Moeller N (2018) Absent agroecology aid: on UK agricultural development assistance since 2010. Sustainability 10(2):505, doi:10.3390/su10020505

Ponisio LC, M'Gonigle LK, Mace KC, Palomino J, de Valpine P, Kremen C (2015) Diversification practices reduce organic to conventional yield gap. Proc Royal Soc B 282(1799):20141396, doi:10.1098/rspb.2014.1396

Poux X, Aubert P-M (2018) An agro-ecological Europe: a desirable, credible option to address food and environmental challenges [online]. IDDRI Issue Brief No 10/18. Retrieved from <https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/D%C3%A9cryptage/201809-IB1018-TYFAEN_0.pdf> [at 10 Dec 2020]

Powell B, Thilsted SH, Ickowitz A, Termote C, Sunderland T, Herforth A (2015) Improving diets with wild and cultivated biodiversity from across the landscape. Food Secur 7:535–554, doi:10.1007/s12571-015-0466-5

Reganold JP, Wachter JM (2016) Organic agriculture in the twenty-first century. Nat Plants 2:15221, doi:10.1038/nplants.2015.221

Smith J, Yeluripati J, Smith P, Nayak DR (2020) Potential yield challenges to scale-up of zero budget natural farming. Nat Sustain 3:247–252, doi:10.1038/s41893-019-0469-x

Snapp SS, Blackie MJ, Gilbert RA, Bezner Kerr R, Kanyama-Phiri GY (2010) Biodiversity can support a greener revolution in Africa. PNAS USA 107(48):20840–20845, doi:10.1073/pnas.1007199107

Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, de Vries W, Vermeulen SJ, Herrero M, Carlson KM, et al. (2018) Options for keeping the food system within environmental limits. Nature 562(7728):519–525, doi:10.1038/s41586-018-0594-0

Timmermann C, Félix GF (2015) Agroecology as a vehicle for contributive justice. Agric Hum Values 32(3):523–538, doi:10.1007/s10460-014-9581-8

Valencia V, Wittman H, Blesh J (2019) Structuring markets for resilient farming systems. Agron Sustain Dev 39:25, doi:10.1007/s13593-019-0572-4

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

Wezel A, David C (2012) Agroecology and the food system. In: Lichtfouse E (ed) Agroecology and strategies for climate change. Sustainable Agriculture Reviews 8, Dordrecht: Springer, 17–34, doi:10.1007/978-94-007-1905-7_2

Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, et al. (2019) Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet Commissions 393(10170):447–492, doi:10.1016/S0140-6736(18)31788-4

Wittman H, Blesh J (2017) Food sovereignty and *fome zero*: Connecting public food procurement programmes to sustainable rural development in Brazil. J Agrar Change 17(1):81–105, doi:10.1111/joac.12131

POSITION PAPER

# A Green Deal for implementing agroecological systems: Reforming the Common Agricultural Policy of the European Union

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Received: May 16, 2020
Revised: December 8, 2020
Accepted: December 9, 2020


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KEYWORDS **agroecology, biodiversity, climate change, ecosystem service, food system, policy, public good, redesign, subsidy, transition**

## 1 Reasons for a fundamental redesign of agricultural systems

The rationale and ambition for a deep redesign of agricultural and food systems in Europe is developed in this paper and based on three main documents: The Treaty on the Functioning of the European Union (TFEU) (EU, 2016), the priorities of the European Commission for the future Common Agricultural Policy (CAP) (EC, 2018) for the 2021–2027 period, and the European "Green Deal" (EC, 2019). The major issues we hereby address are climate change adaptation and mitigation, management of natural resources, conservation and restoration of biodiversity and enhancement of ecosystem services, and economic and societal aspects. Then we outline essential components for an agroecological Green Deal in Europe.

### 1.1 Environmental dimension

Three major documents frame the future of farming and its relationships with environment in the European Union.

First, Article 191 of the TFEU states that "Union policy on the environment shall contribute to pursuit of the following objectives:

- preserving, protecting and improving the quality of the environment,

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- protecting human health,
- prudent and rational utilisation of natural resources,
- promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change".

Second, the European Commission summarised its priorities for the future CAP for the 2021–27 period in nine general objectives reflecting the economic, environmental and social importance of the policy:

1. Support viable farm income and resilience across the European Union (EU) territory to enhance food security;
2. Enhance market orientation and increase competitiveness including greater focus on research, technology and digitalisation;
3. Improve farmers' position in the value chain;
4. Contribute to climate change mitigation and adaptation, as well as to sustainable energy;
5. Foster sustainable development and efficient management of natural resources such as water, soil and air;
6. Contribute to the protection of biodiversity, enhance ecosystem services and preserve habitats and landscapes;
7. Attract young farmers and facilitate business development in rural areas;
8. Promote employment, growth, social inclusion and local development in rural areas, including bio-economy and sustainable forestry;
9. Improve the response of EU agriculture to societal demands on food and health, including safe, nutritious and sustainable food, as well as animal welfare.

Third, the European Green Deal recently recognised that "Food production still results in air, water and soil pollution, contributes to the loss of biodiversity and climate change, and consumes excessive amounts of natural resources, while an important part of food is wasted. At the same time, low quality diets contribute to obesity and diseases such as cancer" (EC, 2019).

Reaching the objectives of the TFEU and the priorities of the future CAP for the 2021–27 period requires a major change in the way agriculture is practiced and a reform of current policies for reducing the negative impacts identified in the European Green Deal.

Conditioning the level of financial support to European farmers to the area they use for their crops or grasslands and the animals they raise, from the budget of the 1st pillar of the CAP, while encouraging them to invest in powerful machinery and large infrastructure on the basis of the 2nd pillar budget, is far from being neutral with regards to the management of natural resources.

The agro-environmental and climatic measures of the 2nd pillar mitigate these effects, but in a very limited way (Kleijn et al., 2006; Pe'er et al., 2017, 2019, 2020). The final results remain largely negative for environmental quality and biodiversity. Biodiversity indicators, e.g. the common farmland bird index, continue to decline while the common forest species index is stable or increases (Pan-European Common Bird Monitoring Scheme, 2020; Pe'er et al., 2014). This situation is hardly surprising as these measures are applied to a modest part of the agricultural area (17 % of the agricultural area in EU27 excluding UK in 2018) (Agri-Food Data Portal, 2018) and only a limited part of these measures efficiently restore biodiversity, while the vast majority of the agricultural area remains hostile.

In the current "CAP vehicle", the 1st pillar acts like an accelerator of environmental degradation, while the 2nd pillar acts partially as a brake. As the 1st pillar benefits from more fuel (budget) than the 2nd, the vehicle continues to move very quickly towards soil degradation, greenhouse gas emissions, loss of biodiversity and destruction of habitats.

However, the CAP is not the only mechanism that fuels the intensification of agriculture. The close relationship between input retailers and farmers is ambiguous. The main farmers' advisers are indeed also the sellers of commercial inputs despite the existence in some countries of advisory services financed by the State. This has led to excessive use of these products (Eurostat, 2013). Input trade and agricultural advice should be separated. Despite of policies to reduce pesticide use there is even an increase as illustrated for example with France which has an increased consumption in the last years by about 14 % (Lamichhane et al., 2019), and has had the highest ever consumption of pesticides in 2018 (Eurostat, 2019).

By exerting a strong pressure on product price, supermarket chains encourage farmers to prioritise yields at the expense of food quality (Mayer, 1997; Marles, 2017). This also leads to excessive input use.

Farmers are currently part of a long industrial chain that starts from a fossil fuel pit and includes also notably the agro-industries that produces inputs, input retailers, agro-food industries that processes agricultural products, and food retailers. It is therefore justified to qualify this agriculture as industrial.

The following sections (1.1.1 to 1.1.4) develop a diagnosis of the current situation regarding the environmental EC priorities for the future CAP.

### 1.1.1 Climate change mitigation and adaptation, and sustainable energy

Soils managed under industrial cropping systems lost a large part of their natural fertility since the early 1960s (Bellamy et al., 2005; Goidts and Van Wesemael, 2007; Gobin et al., 2011; Jones et al., 2011).

The specialisation of farms has led to dramatic simplification of cropping systems, in which crops, livestock and forestry, once integrated, have become separated and intensified, leading to a very high level of specialisation and dependence on external, synthetic inputs (Peeters, 2012). As a consequence, arable land under current industrial systems receive now much less inputs of carbon in the form of farmyard manure or organic residues.

Moreover, deep ploughing and other intensive soil tillage techniques have destroyed soil structure and, together with the intense use of synthetic nitrogen fertiliser, degraded and oxidised soil organic matter, releasing huge amounts of $CO_2$ into the atmosphere (Krištof et al., 2014; Reicosky, 1997).

In addition, the production of soluble nitrogen fertilisers, which are applied widely and in high quantities, requires very large amounts of fossil energy for the industrial fixation of atmospheric nitrogen through the Haber-Bosch process. This process therefore contributes to further significant emission of greenhouse gases (Kyriakou et al., 2020).

Since highly simplified agroecosystems are also very likely to suffer from weeds, pests and diseases outbreaks, agrochemical use, which requires intense use of fossil energy for their production and application), is stable or still growing in some countries (Eurostat, 2020a).

The total energy efficiency of agricultural production has declined considerably in recent decades, being now inversely proportional to the amount of fossil energy injected into the agricultural and food systems. Pimentel and Heichel (1991) calculated for instance energy flows in hand-powered sustainable agricultural systems, in draft animal agricultural and agroforestry systems, and in contemporary intensive agriculture which provides an idea about the historical evolution of energy efficiency of agricultural systems in Europe. It is now estimated that "every calorie of food energy produced and brought to the table represents an average of 7.3 calories of fossil energy inputs" (Heinberg and Bomford, 2009).

Climate change mitigation and adaptation in industrial production systems pose a significant challenge, since the use of few species grown in monocultures with low genetic diversity are much more vulnerable to climate and biotic stresses (Altieri et al., 2015). When combined with low levels of organic matter in soils – that reduces soil water holding capacity and nutrient cycling – it results in strongly decreased resilience of farming systems towards disturbance from climate change (Lal, 2004; Iglesias et al., 2012).

### 1.1.2 Sustainable development and efficient management of natural resources such as soil, water and air

The recent development in agriculture has not led to sustainable and efficient management of natural resources, but rather the contrary. Soils have been heavily degraded since the 1960s, mainly because of the processes referred to in section 1.1.1. They have lost a significant portion of their natural fertility. Their structure has deteriorated, resulting in significant erosion and lower water holding capacity. Soil life has been greatly reduced in biomass and in diversity especially with regard to fungi and earthworms (Hiederer, 2018; Mission Board for Soil health and food, 2020).

The overuse of nitrogen and phosphorus fertilisers and agrochemicals such as herbicides, pesticides and fungicides used in industrial agriculture have polluted many surface and ground water (European Environment Agency, 2018).

The atmosphere has been polluted not only by $CO_2$ emissions caused by the processes described in section 1.1.1, but also by $N_2O$ emissions from synthetic and organic nitrogen fertiliser use. The atmosphere has also been contaminated by some agrochemicals, especially at the time of application to crops, harvest operations and by the excess and improper use of these chemicals (Dubus et al., 2000).

### 1.1.3 Protection of biodiversity, enhancement of ecosystem services and preservation of habitats and landscapes

Sixty years of industrial agriculture have had a huge and unprecedented negative impact on the different forms of biodiversity in rural areas. In fact, overexploitation and agriculture have been recently recognised as the most prevalent threats for several species, especially endangered ones (Maxwell et al., 2016). The mechanisms that explain this biodiversity decline vary by organism and habitat. They can be either physical (e.g. homogenisation of habitat and landscape; elimination of ecological infrastructures; changes in grassland cutting frequencies and stocking rate; ploughing and other intensive tillage practices in arable land), chemical (e.g. application of synthetic nitrogen in grasslands that favours a small number of fast-growing plant species compared to all other species, agrochemicals that directly suppress target and non-target plants, insects or fungi), or mechanical through the traffic of heavy agricultural machinery and the tools used for tillage, weeding and harvesting (e.g. tillage done quickly after harvest thanks to the increasing power of tractors buries fallen grain that become inaccessible to birds that once used them to build up pre-wintering or migration body reserves) (Henle et al., 2008; Pe'er et al., 2014).

These physical, chemical and mechanical mechanisms can be direct or indirect. The use of herbicides, for example, has a direct effect in eliminating or drastically reducing the abundance of dicotyledonous plant species and an indirect action in reducing the abundance of pollinating insects for which these plants are a food source, and that of birds feeding on these insects. The application of pesticides eliminates many of the needed beneficial insects that can reduce crop pests, but also pollinators necessary for the production of fruits and vegetables (Ndakidemi et al., 2016).

Land use change imposed a drastic change in agricultural landscape, generating several detrimental effects to habitats and biodiversity; a main example is the large proportion of hedges and hedgerows networks that have been removed or degraded, to facilitate the movements in the fields of machines of increasing size. Additionally, drainage of wetlands, for "enhancing" the areas and providing new agricultural land, has led to drying of several important biotopes. As a result, many habitats have disappeared from landscapes and been replaced by large, much more uniform blocks of land (Stoate et al., 2001, 2009).

What is now becoming dramatically evident is also that the loss of habitat and biodiversity are contributing to the emergence of diseases in wildlife that may be sources of new severe infections in humans (Sattenspiel, 2001; Johnson et al., 2020)

### 1.1.4 Response of EU agriculture to societal demands on safe, nutritious and sustainable food, as well as animal welfare

The diversity of food products, especially fruits and vegetables, has increased in Europe in recent decades, mainly thanks to the import of tropical products or products long consumed in Europe but produced today in countries of the

South, for example in the counter season. These products do not always meet the Application of Sanitary and Phytosanitary Measures (the "SPS Agreement" of the WTO) (EU, 2000). The production of such fruits and vegetables in these countries can have disastrous consequences. For example, the rapid development of avocado cultivation in Mexico has led to massive deforestation in the wooded mountains of Michoacan[14].

Studies have shown that the nutritional values of many foods have decreased during the 20th century, particularly with regard to their mineral and vitamin content as a result of the use of industrial farming techniques and new more productive cultivars (Mayer, 1997; Marles, 2017).

In the meantime, the European Union has increased its domestic protein production deficit, largely due to a significant gap in legume production for food and feed compared to what is needed, feasible and desirable (Zander et al., 2016). This contributes to diet unbalances in both humans and livestock.

Feeding livestock with grains (cereals, soybean) instead of grass has not only negative environmental implications, but also affects the fatty acid composition of meat and dairy products. Total fatty acids, saturated fatty acids and omega-6/omega-3 levels have increased. In contrast, Combined Linoleic Acid levels, with anti-cancer properties, have declined (French et al., 2000; Alfaia et al., 2009; Saini and Keum, 2018; Davis et al., 2020). A large proportion of grains in livestock diets has also negative impacts on animal health, leading to excessive use of veterinary medicines (EFSA, 2008). This applies to ruminants that can potentially be fed on grass only but also to monogastrics that can use up to 30 to 50 % of grass in their diet (Crawley, 2015; Stødkilde et al., 2018).

However, it is mainly food processing and additions of sugar, saturated fatty acids and salt, downstream of agricultural production, that are known to cause obesity, malnutrition, and related non-communicable diseases (Swinburn et al., 2019). Changes in consumption habits and an increase in the share of processed products in diets are the main cause of major public health problems, with collective costs accounting for 10 to 12 % of total health care costs and that will soon exceed those of alcohol or tobacco-related diseases (WHO/FAO, 2002). Although this is not a direct consequence of the CAP, it should be duly taken into account in an agricultural and food policy approach.

Factory farming of pigs, poultry and sometimes cattle cause promiscuity problems resulting in the spread of diseases, that are partly controlled by antibiotics. Routine and preventative antibiotic use induce the development of resistance phenomena, selecting also human pathogenic bacteria and posing a threat to the entire society. Regarding animal welfare, stress is permanent for these sensitive animals, raised in conditions far from those of their wild ancestors and that do not allow the expression of basic social behaviours (D'Silva, 2006; Anomaly, 2015). Moreover, factory farming creates favourable conditions for the emergence of future human pandemics (Anomaly, 2015).

[14] www.wri.org/blog/2020/02/mexico-avocado-industry-deforestation

## 1.2 Economic dimensions

The importance of agricultural production in the EU, as well as food abundance on supermarket food shelves, give the impression that the system is highly productive. In reality, the agricultural and food system of the EU has become much more import-dependent[15], more unequal, less resilient at both the macro- and micro-economic levels, and finally with a low level of food security and sovereignty. It has also become less value-adding and more value-extracting out of our collective natural capital. This can be reviewed against the CAP objectives, as set out in the treaties. Article 39 of the TFEU (EU, 2016) states that "the objectives of the common agricultural policy shall be":

a) "to increase agricultural productivity by promoting technical progress and by ensuring the rational development of agricultural production and the optimum utilisation of the factors of production, in particular labour";

Far from being optimal, the use of production factors has been strongly skewed by the combined impact of various policies on their relative prices. As in other sectors, the cost of labour, whether self-employed or salaried, is subject to compulsory levies, taxes and social contributions, while investment is helped by subsidies, and in many member states, agricultural fuel oil is benefitting from tax exemption. The main CAP subsidy being paid per hectare also skews the production model in favor of larger farms despite the fact that it is often captured by landowners, not necessarily farmers (Neill and Hanrahan, 2013; Valenti et al., 2020). Hence, labour productivity as measured by value added (VA) per full time equivalent (FTE) (VA/FTE) has been maximised at the expense of other factors of production. This model of specialisation and monoculture has also become increasingly extractive in value on "nature capital" through the destruction of natural assets and the production of negative externalities.

b) "thus to ensure a fair standard of living for the agricultural community, in particular by increasing the individual earnings of persons engaged in agriculture";

The increase in the income of those working in agriculture has been the corollary of the increase in VA/FTE, with a drastic reduction of the labour force in agriculture. A significant segment of farmers is kept below the poverty line promoting a continuous flow of people and families leaving the agricultural sector with social deleterious consequences. This model is economically justified by the fact that it pretends to select the best performing players. It is now clear that rather than a "selection of the fittest", the system selects to a large extent the most "extractive players", in terms of tapping nature capital. The VA of agriculture is largely over-estimated as it hides a value extracted from our collective net asset. For the US, Muller et al. (2011) estimate the gross external damages of agriculture up to 38 % of the VA.

[15] Although, it can be argued that the EU is a net exporter of agricultural products and food, that does not include the direct and indirect dependency on fossil fuels which is nearly entirely imported.

c) "to stabilise markets";

Prices for agricultural inputs and outputs are largely globalised, and the CAP has little influence on them. However, by favouring a specialised agribusiness model that competes globally rather than favouring mixed farms to meet local demand and support local communities, the CAP has exposed an increasing share of farmers to fluctuations in world prices. Farmers find themselves "price takers" in the face of highly concentrated sectors upstream (seeds, fertilisers, equipment) and downstream (purchasing centres from retailers and processing industries). This has contributed to a much faster increase in input prices relative to that of agricultural products, and thus to the erosion of farmers' incomes. Over the last three decades, the output price indices progressed by an average of 1.1 % per year, while the price of most of the inputs increased by around 3 % yearly (own calculations on the basis of data from IMF, World Bank, USDA, Eurostat, Fertilizer International). The deterioration of the "terms of trade" for farmers is illustrated by the contrast between evolution of the VA in volumes which grew steadily over the last two decades by around 0.7 % p.a., while the VA deflated by the consumer prices declined by around -0,8 % p.a. over the same period (Eurostat, 2020b). It should be noted, that after a strong decline in the first decade it started to recover between 2010 and 2018, thanks to the reduction of the intermediate consumption which peaked at 57.7 % of the production in 2009 to decline to 54.1 % in 2018.

d) "to assure the stability of supplies";

Supply security goes hand in hand with the resilience of the sector. While there is a strong decline in environmental resilience (see section 1.1), economic resilience also raises questions both at the farm and macroeconomic levels. At the micro level, the resilience of specialised farms (which are by definition very simplified in terms of products, and exposed to price fluctuations as explained above), is inevitably lower, as evidenced by repeated crises in multiple sub-sectors. At the macro level, the massive dependence of the production model on fossil fuels almost entirely imported from a limited number of non-European regions makes security of supply very precarious in the event of geopolitical or other crises especially in the Middle East or Russia (Darnhofer, 2014).

e) "to assure that supplies reach consumers at reasonable prices".

The CAP has certainly helped to reduce the cost of food for consumers in the available income of European households. However, downward pressure on prices has contributed to the development of production methods that have favoured the quantity and standardisation of products at the expense not only of the environment, but also of the nutritional quality of the products (see section 1.1.4). On the other hand, it would be natural that farmers receive a fair price for their products.

## 1.3 Social and societal aspects

Among the priorities of the European Commission for the future CAP for the 2021–27 period (EC, 2018), priorities 1, 3, 7, 8 and 9 (see section 1.1) are related to social and societal topics.

The social question in agriculture is strongly related to the profitability of farming activities and with risk perception especially by young farmers. Moreover, access to land is difficult for young farmers. The average farmers' age in the EU is close to 55 years. There is a great lack of generational renewal (European Parliament, 2020). The number of farmers is thus still declining very fast (Eurostat, 2018). The number of farms in the EU decreased for instance by about 30 % in the short period between 2005 and 2016 (Eurostat, 2020c). There is a high risk that in 5 to 10 years' time the number of family farms will be extremely low in the EU.

## 1.4 Recent developments

Compared to the former CAP, the current proposition of the European Commission introduced the concept of 'eco-schemes' on top of the existing conditionality rules of the 1st pillar. These eco-schemes complete the range of the 'agro-environmental and climate measures' of the 2nd pillar. The support to organic farming is now included in the eco-schemes. They include also supports to agroforestry, carbon farming, precision farming, and a package of measures such as enhanced crop rotation, better fertilisation, and the implementation of an ecological network on the farm.

The new, enhanced version of conditionality is presented as essential for mitigating climate change, conserving biodiversity, protecting wetlands and peatlands, improving animal welfare and food safety.

If the reform of conditionality and the introduction of the concept of eco-schemes are steps forward for more sustainable systems, they don't adopt a holistic approach and are thus not sufficient for implementing agroecological systems.

The revival of farm independent advisory services is certainly very positive on the condition that advices stimulates farmers to move into the right direction.

Another positive objective is the attempt to build a fairer subsidy distribution system for reducing the inequalities of the current system (about 80 % of the amount of subsidies are distributed to about only 20 % of all beneficiaries). The project is to achieve this objective by the capping of subsidies at 100.000 Euro/year per farm in order to better support small and medium-size farms. Although this objective is laudable, it is unlikely that it will be sufficient for reversing the trend of the fast farmers' population decline.

The CAP has to contribute at least 40 % of climate-related expenditure. However, without a system change the concrete impact on the mitigation of climate change will be modest. Without this change, fossil fuel consumption for the synthesis of nitrogen fertiliser and for agricultural machines for instance, will not be sufficiently reduced. Not enough carbon will be sequestered in agricultural soils. The trend of carbon dioxide and other GHG emissions will be maintained or even increased.

The latitude for member states to largely adapt the European Commission proposals through their national

CAP strategic plans is likely to decrease the efficiency of the CAP reform proposal given the lack of enthusiasm of certain member states to improve the impact of their agricultural systems on the environment.

The 'Farm to Fork strategy' of the Green Deal aims at developing a fairer, healthier and more environmentally friendly food system. With regard to food quality and the stimulation of food processing and retailing by farmers, only an 'Action Plan' has been drafted at this stage. An implementation and financed programme has still to be designed and adopted.

## 2 The principles and goals of the reform

### 2.1 The guiding principles

In 1992, the CAP was radically reformed to integrate the rules of international trade and avoid the perverse effects of the previous policy, including surplus production. Support mechanisms through minimum prices have been replaced by direct aid, mainly per hectare and livestock head.

The perverse effects of the current policy, despite some corrections introduced since then, must lead to a new reform of the same magnitude. It must also be part of the Union's objectives set out in the Green Deal in terms of carbon neutrality by 2050, safeguarding biodiversity, reducing the use of agrochemicals and synthetic fertilisers, and the nutritional quality of production accessible to all.

The two overarching principles of the reform proposed in this paper should be:

First: "Do not harm", the cornerstone of the European Green Deal. This means that all the current measures of the CAP that induce unsustainable production models or behaviours should be phased out.

Second: "Public money for public good". Taxpayers' money should not be used for supporting the production of marketable goods or services, as it introduces market distortions and biases in the production modes. Marketable goods and services should be paid by market prices. This should be helped by favouring production for local markets and value added and differentiated products. Taxpayers' money should be essentially, if not exclusively, used to support the production of public goods such as biodiversity, healthy soils, clean water and air, healthy food, diversified landscapes. A real production of public goods by farmers, that is not remunerated by the market, is expected. This public good production is also a positive element for agricultural production as it conserves and restores agricultural biodiversity and soil fertility.

### 2.2 The main goals of the reform proposed

The main objectives of the CAP as stipulated in Article 39 of the TFEU remain valid and should not be forgotten. They should be implemented with the following additional features to fully embed the sustainability dimension.

#### 2.2.1 Ecologically based agriculture

Climate and biodiversity crises must be taken into account in a new European agricultural and food model. Soil will need to be regenerated by sequestering carbon (Freibauer et al., 2004), improving fertility and increasing their microbial, floral and faunal diversity. This will have the positive effect of controlling pathogens and reducing disease as well as better coping with more frequent and intense weather anomalies. Habitats and agricultural, functional and heritage biodiversity will need to be restored and conserved. This will reduce pest populations. All of this will support mitigation of climate change and increase the resilience of agricultural systems to extreme weather events.

Transformed as such, agriculture will become more resilient and crop yield could be maintained. Nevertheless, agriculture will also have to become less reliant on fossil fuel. It will have to reduce drastically the use of synthetic fertilisers and agrochemicals, and of livestock feed imported from other continents, mostly produced in unsustainable ways. It will have to sell most of its products in short and local food supply chains.

#### 2.2.2 Agricultural aid, climate and biodiversity

The time has come to no longer pay farmers to practice their job according to a business-as-usual model because the pricing mechanisms do not allow them to be paid sufficiently and fairly for their work. Agricultural aids should be paid on the basis of the production of common (or private) goods enjoyed by society as a whole, namely ecosystem services and biodiversity. This would make sense to taxpayers and give agriculture new prospects.

The European Green Deal stipulates that "European farmers and fishermen are key to managing the transition. The Farm to Fork Strategy will strengthen their efforts to tackle climate change, protect the environment and preserve biodiversity. The common agricultural and common fisheries policies will remain key tools to support these efforts while ensuring a decent living for farmers, fishermen and their families". The Commission's proposals for the Common Agricultural Policy for 2021 to 2027 stipulate that "at least 40 % of the common agricultural policy's overall budget and at least 30 % of the Maritime Fisheries Fund would contribute to climate action" (EC, 2019).

#### 2.2.3 Maintaining family farms and vibrant rural communities

Creating new perspectives for European family farms would require increasing their profitability by decreasing production costs, especially those of commercial inputs, and increasing revenue by targeting quality products, by processing the products and selling them in short and local supply chains, at least partly. Complementary activities such as agritourism or part-time jobs are also possible solutions. Decreasing input use is feasible by replacing fossil-fuel based products by the ecosystem services provided by biodiversity (e.g. nitrogen fertilisers by biologically fixed nitrogen by legumes, insecticides by natural enemies of crop pests). This is perfectly possible since species of the agroecosystem can biologically fix large amounts of nitrogen, can regulate weeds, pests and diseases, support recycling of nutrients, and secure pollination and other vital functions. This requires the strong development of agroecological practices (Wezel et al., 2014) on large scales for the restoration of soil life with reduced or no-tillage; continuous soil cover; direct seeding into cover crops; the development of a dense ecological network (such as herbaceous strips or hedges); the choice of climate-resilient crop species, cultivars and mixtures; intercropping (including agroforestry); long and diversified crop rotations; crop/livestock integration; rotational grazing; and the use of low-demanding livestock breeds that can transform grass into meat, eggs and dairy products.

Adopting these practices, measures and strategies would greatly facilitate the transmission of farms to the next generation, but would also stimulate the creation of jobs in related processing and marketing activities. Maintaining farms in rural areas is also an opportunity to develop new activities in these areas if economic activities are re-localised, thus also contributing to the social revitalisation of rural territories and therefore to rural development.

Since small-scale family farms get much less support than large industrial farms while they create more jobs per hectare, this trend should be counteracted by an adequate mechanism, supporting people and not hectares.

### 2.2.4 The systemic approach of agroecology

Dealing with crises, developing a system that is truly up to the challenge and adopting a systemic approach is essential. Only this approach can, with the support of analytical approaches, respond to the above-mentioned stringent issues. This approach should integrate environmental, social and economic components while being technically realistic. With regard to the restoration of biodiversity, this ecologically based system should provide favourable conditions for life forms on the entire agricultural area and not only on a limited area of land.

This system approach exists, and its name is agroecology. It has been defined by the Food and Agriculture Organization of the United Nations (FAO) in its memorandum "The 10 Elements of Agroecology" (FAO, 2018) and, in an even more detailed manner, in the report of a FAO High-Level Panel of Experts on food security and nutrition (HLPE, 2019). Agroecology became increasingly institutionalised within United Nations Organizations (Loconto and Fouilleux, 2019).

The agroecological approach redesigns the conventional agricultural system based on the principle that the role of external inputs can be replaced, or at least strongly reduced, by ecological processes, while production levels can be maintained.

Thanks to its systemic approach explained above, agroecological systems are often more profitable than industrial agriculture as recently shown by a panel of around thirty European scientists (van der Ploeg et al., 2019).

Other agricultural systems or techniques are related to agroecology, such as organic farming, biodynamic agriculture, permaculture, conservation agriculture, agroforestry, low-input agriculture, carbon farming, or integrated pest control. The most widespread and known system, organic farming, may be represented by farms that are more or less agroecological because they adopt agroecology principles to a variable extent. Organic farms are recognised as organic because they respect the official organic specifications under a label, and which gives them access to higher subsidies and usually higher prices for their products. The respect of these rules is certainly not always sufficient for concluding that a farm is agroecological, but it is widely acknowledged that organic farming contributed significantly to the implementation of more sustainable agricultural systems well beyond the boundaries of this system (EC, 2019). In contrast, there is no agroecological label, yet. Agroecology is a process of progress based on a progressive adoption of the complete set of agroecological principles. It is the systemic combination of specific practices related to the set of principles that generates the characteristics and results described above.

## 3 Measures for an agroecological CAP

### 3.1 Support people not hectares

Current subsidies to European agriculture have led to a very strong distortion of the relative costs of production factors in favour of surface, energy and capital intensity and against labour. This distortion has led to highly extractive and unsustainable production models which also contribute to job redundancy, unemployment and overexploitation of socially weaker workers. That is a clear breach to the "Do not harm" principle. Just as the energy transition begins with the phasing out of fossil fuel subsidies, the new CAP must abandon subsidies to unsustainable practices and/or conflicting with the EU's environmental and social objectives.

In general, agricultural practices compatible with respect for the environment, the fight against climate change, short circuit feeding, etc. are more labour intensive. It is therefore counterproductive to maintain a policy that subsidises most factors of production except the most crucial one: labour.

The replacement of subsidies per hectare (or per livestock head) with a base income per FTE would correct this distortion, at least partially, given the usual social and income tax levies. This base income would be conditional on strict compliance with environmental rules, to a declared activity on a farm.

This base income could be financed not only by the phasing out of the current pillar 1 subsidies that are distributed on a surface basis, but also by the introduction of charges on practices that contribute to depleting our common natural capital (use of agrochemical or chemical fertilisers), based on the "polluter pays" principle.

In addition, innovative approaches could be developed to sustain the thousands of seasonal workers employed in agriculture that are living in precarious conditions.

### 3.2 Public money to produce public goods

European agriculture provides, or has the potential to provide, public (or common) goods that benefit society as a whole. Among these, the three main public goods are the sequestration of carbon in agricultural soils, the restoration of rural biodiversity and the development of the ecological network that structures landscapes.

Ecosystem services are declining, and they are better provided by small-scale farms in a heterogeneous landscape matrix (Perfecto and Vandermeer, 2010). However, small-scale family farms get much less support than large industrial farms. This would be corrected by the basic farmer income proposed in section 3.1, strongly conditioned on good environmental practices, including on compliance with reduction of nutrient excess and pesticide dependency.

As a complement to the former measure (see section 3.1), replacing EU and national current subsidies per hectare or by livestock head by direct payments for the production of public goods in the context of a quality food production would give meaning to the CAP. From the farmers' point of view, they would no longer be paid to do their ordinary job only, as seen to provide high yields for different commodities. The present monetary support is a kind of assistance because of the insufficient profitability of their activity. The future should be the production of common goods that are not otherwise paid because they are not marketable. From the citizens' point of view, their taxes will no longer be spent to the bottom of a profit to subsidise a declining sector but for the actual production of public goods which they can enjoy and profit concretely in a long-term perspective.

The payment per ton of carbon sequestered in soils can be based on two alternative systems: periodic and geo-localised analysis of soil carbon content or the adoption of a fairly simple grid that assesses carbon sequestration on the basis of agricultural practices. When these amounts of carbon are assessed, a value must be assigned to the ton of carbon that is high enough to motivate farmers to opt for sustainable practices (Eco-Logic et al., 2020). The subsidies would be reverted in case of reversal of the practices, in application of the polluter-payer principle.

The payment based on the length, the density and quality of ecological networks is easy to implement. These data can be measured by a combination of aerial detection (remote sensing) and field record. Then a price must be given to the quantity of each type of habitat.

Several agricultural practices, in particular various agroecological practices, that sequester carbon in soils are also those that restore, conserve or enhance soil and aboveground biodiversity. Moreover, the development of the ecological network is the basis for the recovery of biodiversity that could spread above the soil surface. However, additional measures in favour of biodiversity are to be foreseen for the conservation of certain habitats or species. Moreover, the current agro-environmental schemes provide a good basis for pricing these measures.

All these public good related measures supported by direct payments have the potential to improve net income of farmers and resilience of the agricultural production. The two previous main measures, “Support people not hectares” and “Public money for public goods”, constitute the two pillars of the reform proposal. The first one aims at stabilising farmer’s populations and should thus be seen as transitional. It should be abolished when the objective is reached, the second measure becoming the central one. The main measures have to be completed by accompanying measures.

## 3.3 Other measures supporting the transition towards agroecology

Even if agroecological farming appears to be more profitable than industrial agriculture on the medium-term (van der Ploeg et al., 2019), farmers who want to convert to agroecological farming face difficulties in the first years. They have to make new investments, while soil fertility restoration and adaptation of cropping practices take time, and new markets have to be developed. New tools adapted to agroecological systems and practices are needed. Transition towards a new system is thus difficult and risky.

The implementation of a training network with well-trained advisers in transition towards agroecological systems is therefore essential. Their role would be to mentor farmers’ groups. They will help the majority of farmers to avoid the mistakes of the pioneers of agroecology. They will facilitate and speed up the transition and adaptation of agroecological practices to the local pedo-climatic and socio-economic context.

A network of innovative agroecological farms should be set up and promoted. These farms could be used as “agroecological lighthouses from which principles may radiate out to local communities, helping them to build the basis of an agricultural strategy that promotes efficiency, diversity, synergy, and resiliency” (Nicholls and Altieri, 2018).

The reduction of current subsidies for large machines and buildings will free financial means for the creation of a new fund for facilitating the development and purchase of agroecological tools and equipment.

Creating land banks (inspired by the French “SAFER”[16] and other examples) at European scale or in all member states would facilitate young and small farmers to buy or rent land on the basis of a project that is relevant and consistent with the goals of the ‘Green Deal’ and the future ‘Farm to Fork’ programme.

All the previous supporting measures should be co-financed by member states.

In coherence with the Green Deal, the CAP should be coordinated with other policies. The context and the rationale of this cross-cutting approach cannot be described and justified in this document. It can just be said that this coordination between the CAP and other policies and the private sector is necessary for questions of policy coherence and efficiency.

The phasing out of subsidies on fossil energy and external inputs should be implemented in coordination with other EU policies and the phasing out of loans to fossil fuel extraction and to industrial nitrogen fixation in coordination with the private sector (notably banks).

The CAP should also be coordinated with public health policies and the private sector for reducing food waste and combat obesity, malnutrition, and related non-communicable diseases.

[16] www.safer.fr

## 4 Conclusion

The policy proposed in this paper should result in a better distribution of income for farmers and overall a better margin for their activities. The public good production would be supported by taxpayer money, while food production margins would benefit from the reduction of costly inputs while the reorientation of the production toward quality products, local markets and value productions should result in better prices. Increasing the share of the production devoted to the local market and alternative distribution channels, would increase the contractual power of farmers as relative to concentrated industrial buyers. Overall, the exposure to the volatility of world prices would be significantly mitigated.

The value for the final consumer would increase in line with the improved nutritional quality of the products. This should not necessarily be seen as a negative issue undermining people's spending power. It should rather be seen as an opportunity to rebalance distribution of added value along the food supply chain, while providing consumers with acceptable price, better quality food which is value for money, empowering them, and reducing food waste. First, fair distribution of added value and adequate remuneration of farmers will be favoured by short food supply chains typical of agroecological production. Second, increased supply of high quality, local and seasonal food will favour rebalancing of food offer and supply thereby diminishing food waste. Third, fostering agroecological food systems will (re)educate consumers towards values like seasonality of production or avoidance of mass purchase of non-fresh and overly processed food, and make them aware that they can play an active role in fostering local socio-economic wealth, and in sustaining their own and environmental health. In this way, consumers will also learn what is the dark side of cheap food (unbalanced added value distribution, unfair remuneration of farmers, environmental degradation, borderline or illegal exploitation of seasonal and migrant work).

Lastly, as negative externalities of the present industrial agricultural systems are paid currently by taxpayers, reducing them will allow reducing needed taxes (to fund also the CAP and health care systems) which could counterbalance the potential increase of final food prices for consumers as mentioned above.

## Acknowledgements

We are grateful to the LIFE Program of the European Union and the Fondation de France which financially supported Agroecology Europe. We highly acknowledge the comments and correction of the three reviewers of this paper which strongly helped to improve the paper.

### REFERENCES

Agri-Food Data Portal (2018) Environment and Climate Action (Summary) – (EU27) – European Union 27 (excluding UK) [online]. Retrieved from <https://agridata.ec.europa.eu/extensions/DashboardIndicators/Environment.html> [at 01 Dec 2020]

Alfaia CPM, Alves SP, Martins SIV, Costa ASH, Fontes CMG, Lemos JPC, Bessa RJB, Prates JAM (2009) Effect of the feeding system on intramuscular fatty acids and conjugated linoleic acid isomers of beef cattle, with emphasis on their nutritional value and discriminatory ability. Food Chem 114(3):939–946, doi:10.1016/j.foodchem.2008.10.041

Altieri MA, Nicholls CI, Henao A, Lana MA (2015) Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev 35: 869–890, doi:10.1007/s13593-015-0285-2

Anomaly J (2015) What's wrong with factory farming? Public Health Eth 8(3): 246–254, doi:10.1093/phe/phu001

Bellamy PH, Loveland PJ, Bradley RI, Lark RM, Kirk GJD (2005) Carbon losses from all soils across England and Wales 1978–2003. Nature 437:245–248, doi:10.1038/nature04038

Crawley K (2015) Fulfilling 100 % organic pig diets: Feeding roughage and foraging from the range [online]. ICOPP Technical note 4, 4 p. Retrieved from <https://www.agricology.co.uk/sites/default/files/ICOPP_Technical_Note_4.pdf> [at 23 Dec 2020]

Darnhofer I (2014) Resilience and why it matters for farm management. Eur Rev Agric Econ 41(3):461–484, doi:10.1093/erae/jbu012

Davis H, Chatzidimitriou E, Leifert C , Butler G (2020) Evidence that forage-fed cows can enhance milk quality. Sustainability 12(9):3688, doi:10.3390/su12093688

Dubus IG, Hollis JM, Brown CD (2000) Pesticides in rainfall in Europe. Environ Pollut 110(2):331–344, doi:10.1016/S0269-7491(99)00295-X

D'Silva J (2006) Adverse impact of industrial animal agriculture on the health and welfare of farmed animals. Integr Zool 1(1):53–58, doi:10.1111/j.1749-4877.2006.00013.x

EC, European Commission (2018) EU Budget: the Common Agricultural Policy beyond 2020 [online]. Fact Sheet, 8 p. Retrieved from <https://ec.europa.eu/commission/presscorner/detail/en/MEMO_18_3974> [at 23 Dec 2020]

EC, European Commission (2019) The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions [online]. 24 p. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN> [at 23 Dec 2020]

Eco-Logic, COWI, IEEP (2020) Carbon farming schemes in Europe – Roundtable. Background document [online]. European Commission, Directorate-general Climate Action, 23 p. Retrieved from <https://www.ecologic.eu/sites/files/presentation/2019/cf_roundtable_background_04102019_final.pdf> [at 23 Dec 2020]

EFSA, European Food Safety Authority (2008) Scientific report on the effects of farming systems on dairy cow welfare and disease. Report of the Panel on animal health and Welfare. Annex EFSA J 1143)1–38, doi:10.2903/j.efsa.2009.1143r

EU, European Union (2000) Council Directive 2000/29/EC of 8 May 2000 on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community (Article 35) [online]. OJ L 169, 10.7.2000, 112 p. Retrieved from <http://data.europa.eu/eli/dir/2000/29/oj> [at 23 Dec 2020]

EU, European Union (2016) Consolidated version of the Treaty on the Functioning of the European Union [online]. C 202, 7.6.2016, 388 p. Retrieved from <http://data.europa.eu/eli/treaty/tfeu_2016/oj> [at 23 Dec 2020]

European Environment Agency (2018) Chemicals in European water. Knowledge developments [online]. EEA Report 18, 76 p. Retrieved from <https://www.eea.europa.eu/publications/chemicals-in-europe-an-waters>

European Parliament (2020) Demographic outlook for the European Union 2020 [online]. Retrieved from <https://www.europarl.europa.eu/RegData/etudes/STUD/2020/646181/EPRS_STU(2020)646181_EN.pdf> [at 23 Dec 2020]

Eurostat (2013) Agri-environmental indicator – pesticide pollution of water [online]. Retrieved from <http://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Agri-environmental_indicator_-_pesticide_pollution_of_water> [16 March 2018]

Eurostat (2018) Agriculture, forestry and fishery statistics – 2018 edition. Luxembourg: Publications Office of the European Union, 195 p, doi:10.2785/340432

Eurostat (2019) Agri-environmental indicator – consumption of pesticides [online]. Retrieved from <https://ec.europa.eu/eurostat/statistics-ex-

plained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides> [at 23 Dec 2020]

Eurostat (2020a) Pesticide sales [online]. Retrieved from <https://ec.europa.eu/eurostat/web/products-datasets/-/aei_fm_salpest09> [at 27 Nov 2020]

Eurostat (2020b) Data from EU 10 western countries (BE, DK, GR, IE, SP, IT, FR, NL, AU, PO) [online]. Retrieved from <https://ec.europa.eu/eurostat/> [at 27 Nov 2020]

Eurostat (2020c) Farms and farmland in the European Union – statistics [online]. Retrieved from <https://ec.europa.eu/eurostat/statistics-explained/index.php/Farms_and_farmland_in_the_European_Union_-_statistics#The_evolution_of_farms_and_farmland_from_2005_to_2016> [at 27 Nov 2020]

FAO (2018) The 10 elements of agroecology. Guiding the transition to sustainable food and agricultural systems [online]. Rome: FAO, 15 p. Retrieved from: <http://www.fao.org/3/i9037en/i9037en.pdf> [at 01 Dec 2020]

Freibauer A, Rounsevell MDA, Smith P, Verhagen J (2004) Carbon sequestration in the agricultural soils of Europe. Geoderma 122(1):1–23, doi:10.1016/j.geoderma.2004.01.021

French P, Stanton C, Lawless F, O'Riordan EG, Monahan FJ, Caffrey PJ, Moloney AP (2000) Fatty acid composition, including conjugated linoleic acid, of intramuscular fat from steers offered grazed grass, grass silage, or concentrate-based diets. J Anim Sci 78(11):2849–2855, doi:10.2527/2000.78112849x

Gobin A, Campling P, Janssen L, Desmet N, van Delden H, Hurkens J, Lavelle P, Berman S (2011) Soil organic matter management across the EU – best practices, constraints and trade-offs. Final Report for the European Commission's DG Environment, 150 p, doi:10.2779/17252

Goidts E, Van Wesemael B (2007) Regional assessment of soil organic carbon changes under agriculture in Southern Belgium (1955–2005). Geoderma 141(3–4):341–354, doi:10.1016/j.geoderma.2007.06.013

Heinberg R, Bomford M (2009) The food and farming transition: Toward a post-carbon food system. Sebastopol, USA: Post Carbon Institute, 41 p

Henle K, Alard D, Clitherow J, Cobb P, Firbank L, Kull T, McCracken D, Moritz RFA, Niemelä J, Rebane M, et al. (2008) Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe – A review. Agric Ecosyst Environ 124(1–2):60–71, doi:10.1016/j.agee.2007.09.005

Hiederer R (2018) Data evaluation of LUCAS soil component laboratory 2009 to 2015 data for soil organic carbon [online]. JRC Technical report: JRC1 12711. Retrieved from <https://esdac.jrc.ec.europa.eu/public_path/shared_folder/JRC112711_lucas_oc_data_evaluation_final.pdf> [at 01 Dec 2020]

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome: HLPE c/o FAO, 163 p. Retrieved from <http://www.fao.org/3/ca5602en/ca5602en.pdf> [at 1 Dec 2020]

Iglesias A, Quiroga S, Moneo M, Garrote L (2012) From climate change impacts to the development of adaptation strategies: Challenges for agriculture in Europe. Climatic Change 112:143–68, doi:10.1007/s10584-011-0344-x

Johnson CK, Hitchens PL, Pandit PS, Rushmore J, Evans TS, Young CCW, Doyle MM (2020) Global shifts in mammalian population trends reveal key predictors of virus spillover risk. Proc R Soc B 287(1924):20192736, doi:10.1098/rspb.2019.2736

Jones A, Panagos P, Barcelo S, Bouraoui F, Bosco C, Dewitte O, Gardi C, Erhard M, Hervás J, Hiederer R, et al. (2011) The state of soil in Europe. A contribution of the JRC to the EEA Environment State and Outlook Report – SOER 2010, doi:10.2788/77361

Kleijn D, Baquero RA, Clough Y, Díaz M, De Esteban J, Fernández F, Gabriel D, Herzog F, Holzschuh A, Jöhl R, et al. (2006) Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecol Lett 9(3):-243–254, doi:10.1111/j.1461-0248.2005.00869.x

Krištof K, Šima T, Nozdrovický L, Findura P (2014) The effect of soil tillage intensity on carbon dioxide emissions released from soil into the atmosphere. Agronomy Research 12(1):115–120

Kyriakou V, Garagounis I, Vourros A, Vasileiou E, Stoukides M (2020) An electrochemical Haber-Bosch Process. Joule 4(1):142–158, doi:10.1016/j.joule.2019.10.006

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304(5677):1623–1627, doi:10.1126/science.1097396

Lamichhane JR, Messéan A, Ricci P (2019) Research and innovation priorities as defined by the Ecophyto plan to address current crop protection transformation challenges in France. Chapter Two. Adv Agron 154:81–152, doi:10.1016/bs.agron.2018.11.003

Loconto AM, Fouilleux E (2019) Defining agroecology: Exploring the circulation of knowledge in FAO's Global Dialogue. Int J Sociol Agric Food 25 (2):116–137, doi:10.48416/ijsaf.v25i2.27

Marles RJ (2017) Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines. J Food Compos Anal 56:93–103, doi:10.1016/j.jfca.2016.11.012

Maxwell SL, Fuller RA, Brooks TM, Watson JE (2016) Biodiversity: The ravages of guns, nets and bulldozers. Nature News 536(7615): 143–145, doi:10.1038/536143a

Mayer AM (1997) Historical changes in the mineral content of fruits and vegetables. Brit Food J 99(6):207–211, doi:10.1108/00070709710181540

Mission Board for Soil health and food (2020) Caring for soil is caring for life. Ensure 75 % of soils are healthy by 2030 for healthy food, people, nature and climate. Interim Report, 78 p, doi:10.2777/918775

Muller NZ, Mendelsohn R, Nordhaus W (2011) Environmental accounting for pollution in the United States economy. Am Econ Rev 101(5):1664, doi:10.1257/aer.101.5.1649

Ndakidemi B, Mtei K, Ndakidemi PA (2016) Impacts of synthetic and botanical pesticides on beneficial insects. Agric Sci 7(6):364–372, doi:10.4236/as.2016.76038

Neill SO, Hanrahan K (2013) An analysis of the capitalisation of CAP payments intoland rental rates in Ireland [online]. Factor Markets, Working Paper 68, 27 p. Retrieved from <http://aei.pitt.edu/58612/1/Factor_Markets_68.pdf> [at 23 Dec 2020]

Nicholls C, Altieri MA (2018) Pathways for the amplification of agroecology. Agroecol Sustain Food 42(10):1170–1193, doi:10.1080/21683565.2018.1499578

Pan-European Common Bird Monitoring Scheme (2020) European indicators [online]. Retrieved from <https://pecbms.info/trends-and-indicators/indicators/> [at 01 Dec 2020]

Peeters A (2012) Past and future of European grasslands. The challenge of the CAP towards 2020. In: Golinski P, Warda M, Stypinski P (eds) Grassland – a European resource? Poznán:Polish Grassland Society, Grassland Science in Europe 17:17–32

Perfecto I, Vandermeer J (2010) The agroecological matrix as alternative to the land-sparing/agriculture intensification model. PNAS USA 107(13): 5786–5791, doi:10.1073/pnas.0905455107

Pe'er G, Bonn A, Bruelheide H, Dieker P, Eisenhauer N, Feindt PH, Hagedorn G, Hansjürgens B, Herzon I, Lomba Â, et al. (2020) Action needed for the EU Common Agricultural Policy to address sustainability challenges. People Nat 2(2):305–316, doi:10.1002/pan3.10080

Pe'er G, Dicks LV, Visconti P, Arlettaz R, Báldi A, Benton TG, Collins S, Dieterich M, Gregory RD, Hartig F, et al. (2014) EU agricultural reform fails on biodiversity. Science 344(6188):1090–1092, doi:10.1126/science.1253425

Pe'er G, Lakner S, Müller R, Passoni G, Bontzorlos V, Clough D, Moreira F, Azam C, Berger J, Bezak P, et al. (2017) Is the CAP fit for purpose? An evidence-based fitness-check assessment. Leipzig: German Centre for Integrative Biodiversity Research (iDiv), 20 p

Pe'Er G, Zinngrebe Y, Moreira F, Sirami C, Schindler S, Müller R, Bontzorlos V, Clough D, Bezák P, Bonn A, et al. (2019) A greener path for the EU Common Agricultural Policy. Science 365(6452):449–451, doi:10.1126/science.aax3146

Pimentel D, Heichel GH (1991) Energy efficiency and sustainability of farming systems. In: Lal R, Pierce FJ (eds) Soil management for sustainability. Ankeney, USA: Soil and Water Conservation society, 113–123 ref. 42

Reicosky DC (1997) Tillage-induced $CO_2$ emission from soil. Nutr Cycl Agroecosyst 49:273–285, doi:10.1023/A:1009766510274

Saini RK, Keum YS (2018) Omega-3 and omega-6 polyunsaturated fatty acids: Dietary sources, metabolism, and significance – A review. Life Sci 203: 255–267, doi:10.1016/j.lfs.2018.04.049

Sattenspiel L (2001) Tropical environments, human activities, and the transmission of infectious diseases. Am J Phys Anthropol 113(S31)3–31, doi:10.1002/1096-8644(2000)43:31+<3::AID-AJPA2>3.0.CO;2-Z
Stoate C, Baldi A, Beja P, Boatman ND, Herzon I, van Doorn A, de Snoo GR, Rakosy L, Ramwell C (2009) Ecological impacts of early 21st century agricultural change in Europe – A review. J Environ Manage 91(1):22–46, doi:10.1016/j.jenvman.2009.07.005
Stoate C, Boatman ND, Borralho R, Rio Carvalho C, de Snoo G, Eden P (2001) Ecological impacts of arable intensification in Europe. J Environ Manage 63(4):337–365, doi:10.1006/jema.2001.047
Stødkilde L, Damborg VK, Jørgensen H, Laerke HN, Jensen SK (2018) White clover fractions as protein source for monogastrics: dry matter digestibility and protein digestibility-corrected amino acid scores. J Sci Food Agric 98(7):2557–2563, doi:10.1002/jsfa.8744
Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, Brinsden H, Calvillo A, De Schutter O, Devarajan R, et al. (2019) The global syndemic of obesity, undernutrition, and climate change: The Lancet Commission report. Lancet 393(10173):791–846, doi:10.1016/S0140-6736(18)32822-8
Valenti D, Bertoni D, Cavicchioli D, Olper A (2020)The capitalization of CAP payments into land rental prices: a grouped fixed-effects estimator. Appl Econ Lett 1–6, doi:10.1080/13504851.2020.1749227
van der Ploeg JD, Barjolle D, Bruil J, Brunori G, Costa Madureira LM, Dessein J, Drąg Z, Fink-Kessler A, Gasselin P, Gonzalez de Molina M, et al. (2019) The economic potential of agroecology: Empirical evidence from Europe. J Rural Stud 71:46–61, doi:10.1016/j.jrurstud.2019.09.003
Wezel A, Casagrande M, Celette F, Vian JF, Ferrer A, Peigné J (2014) Agroecological practices for sustainable agriculture. A review. Agron Sustain Dev 34:1–20, doi:10.1007/s13593-013-0180-7
WHO/FAO (2002) Diet, nutrition and the prevention of chronic diseases: report of the joint WHO/FAO expert consultation, Geneva. WHO technical report series 916, 149 p. Retrieved from <https://www.who.int/dietphysicalactivity/publications/trs916/download/en/> [at 23 Dec 2020]}
Zander P, Amjath-Babu TS, Preissel S, Reckling M, Bues A, Schläfke N, Kuhlman T, Bachinger J, Uthes S, Stoddard F, et al.(2016) Grain legume decline and potential recovery in European agriculture: a review. Agron Sustain Dev 36(2):26, doi:10.1007/s13593-016-0365-y

REVIEW ARTICLE

# Organic food and farming in West Africa: A systematic review

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Received: July 01, 2020
Revised: September 04, 2020
Accepted: September 21, 2020

HIGHLIGHTS

- **There is a huge gap in research on organic food and farming in West Africa particularly in Cape Verde, Gambia, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mauritania, Niger, Sierra Leone and Togo.**
- **The analysed literature indicates that organic agriculture can support climate change mitigation and adaptation, conserve biodiversity, reduce environmental impacts, and enhance livelihoods of farming households.**
- **Different factors hinder the development of organic agriculture in West Africa, e.g. agricultural policy, agronomic research, institutional environment and extension management.**
- **There is a need to strengthen research on organic food and farming in West Africa in order to fill the existing knowledge gap and unlock the sector potential.**

KEYWORDS **agriculture policy, agroecology, biodiversity, climate change, food security, organic agriculture, rural livelihoods, Sahel, sub-Saharan Africa**

## Abstract

Organic agriculture can play a pivotal role in addressing different challenges (e.g. poverty, biodiversity loss, climate change). However, organic agriculture is 'knowledge intensive' and its development requires investments in research and innovation. This systematic review casts light on research on organic food and farming (OFF) in West Africa. It draws upon a search performed in April 2020 on the Web of Science. An overview of both bibliometrics and topics addressed in the analysed literature is provided. The analysed literature indicates that organic agriculture can support climate change mitigation and adaptation, conserve biodiversity and reduce environmental impacts. However, the comparative performance of organic farming is site-specific. Similarly, the organic-conventional yield gap depends, inter alia, on crops and cropping practices. Furthermore, different factors hinder the development of OFF in West Africa, which include agricultural policy, agronomic research, institutional environment and extension management, among others. The study concludes that organic agriculture is poorly developed in West Africa. Therefore, it is recommended that awareness on OFF should be raised, organic farmers supported and research on organic farming strengthened to fill the existing knowledge gap and unlock the sector potential.

## 1 Introduction

Organic agriculture is an important alternative to conventional agriculture that can support the Sustainable Development Goals (SDGs) (Setboonsarng and Gregorio, 2017; de Schaetzen, 2019). There has been an increasing demand for organic agri-food products due to the growing consumers' awareness in recent decades. Recent data show that organic agriculture was practiced worldwide by 2.8 million farmers on 71.5 million hectares in 2018. Meanwhile, the market of organic food and drink was worth about $96 \cdot 10^9$ EUR worldwide (Willer and Lernoud, 2020).

There is a growing body of scientific evidence on the positive effects of organic farming practices in terms of promoting natural resources conservation (Maeder et al., 2002; Gattinger et al., 2012; Gabriel et al., 2013; Tsiafouli et al., 2015; Helm, 2019), reducing emissions (Scialabba and Müller-Linden-

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lauf, 2010; Tuomisto et al., 2012; Muller et al., 2017), decreasing resources (e.g. water and energy) consumption (Tuomisto et al., 2012; de Porras Acuna et al., 2018), and improving the provision of ecosystem services (Sandhu et al., 2010; Robertson et al., 2014; Reganold and Wachter, 2016). Organic agriculture is also associated with the conservation of both natural biodiversity and agro-biodiversity (Bengtsson et al., 2005; Asigbaase et al,. 2019). Furthermore, organic farming performs well in terms of social and economic indicators (Kilcher, 2007; Hammas and Ahlem, 2017) and generates high quality products (Kluger, 2010; Reganold and Wachter, 2016; Seufert et al., 2017). Some studies suggest lower yields in organic farms (Seufert et al., 2012; Tuomisto et al., 2012; Reganold and Wachter, 2016), which may have implications in terms of achieving food security (de Ponti et al., 2012; Seufert et al., 2012; Ponisio et al., 2015; Reganold and Wachter, 2016). Some authors note that organic yields are sometimes higher than conventional ones in developing countries (de Bon et al., 2019). Moreover, the outcomes of comparing organics and conventional agriculture depend on the production context and conditions (Seufert et al., 2012). Indeed, organic farming seems relatively more efficient and productive in developing countries (Gomiero et al., 2011; Niggli, 2015; Hammas and Ahlem, 2017; Jouzi et al., 2017; Lori et al., 2017; Qiao et al., 2018). As a result, organic farming is increasingly promoted as a means to address the problems of food insecurity and poverty among farming households and rural communities in the developing world (Setboonsarng and Gregorio, 2017; Adebiyi et al., 2019). Furthermore, frequent food safety incidents and increased consumers' health awareness are associated with an increase in the consumption of organic foods (Hsu et al., 2016; Zwierzchowski and Ametaj, 2018).

Many scholarly publications and technical reports highlight the environmental, social and economic benefits of organic farming, especially in developing countries (Kilcher, 2007; Seufert, 2012; Setboonsarng and Gregorio, 2017). Organic agriculture plays an important role in the development of rural areas in developing countries (IFAD, 2016). In this context, there is a growing interest in the development of organic agriculture across Africa. According to UNCTAD and UNEP (2008), "Organic agricultural systems are making a significant contribution to the reduction of food insecurity and poverty in areas of Africa, and to an improvement in rural livelihoods". Gama and Amudav (2020) suggest that "Organic agriculture (known as ecological organic agriculture in Africa) has gained momentum and grown in recognition among farmers, practitioners, policymakers and other stakeholders for its significant role in addressing food insecurity, land degradation, poverty, and climate change among other benefits" (p. 186).

Many scholars and practitioners highlight the potential of West Africa in organic agriculture (Smith, 2010; De Bon et al., 2018). However, West Africa (viz. Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo) lags behind in terms of organic agriculture development compared with Northern (e.g. Tunisia, Egypt) and Eastern (e.g. Tanzania, Uganda, Kenya, Ethiopia) Africa. Indeed, the share of total agricultural land under organic management in West Africa ranges from between about 0.0001 % in Guinea, Liberia and Niger to 2.5 % in Sierra Leone (*Table 1*).

One of the reasons for such weak development of organic food and farming in West Africa might be the lack of research and development. Indeed, organic farming is often described as being 'knowledge intensive' (Bliss et al. 2019) and its development requires substantial investments in research and innovation. However, there has been no comprehensive assessment of research so far in the region. This paper reviews the scholarly literature on organic food and farming in West Africa indexed in the Web of Science (WoS) to address this deficiency.

**TABLE 1**
Structure of organic farming in West Africa

| Country* | Organic area [ha] | Share of organic area in total agricultural land [%] | Producers [no.] |
|---|---|---|---|
| Benin | 16,454 | 0.4 | 4,030 |
| Burkina Faso | 56,663 | 0.5 | 26,627 |
| Cape Verde | 495 | 0.6 | NA |
| Côte d'Ivoire | 50,574 | 0.2 | 2,776 |
| Gambia | 20 | 0.003 | NA |
| Ghana | 29,663 | 0.2 | 3,228 |
| Guinea | 10 | 0.0001 | NA |
| Guinea-Bissau | 835 | 0.1 | NA |
| Liberia | 2 | 0.0001 | NA |
| Mali | 12,655 | 0.03 | 12,272 |
| Niger | 254 | 0.001 | 2 |
| Nigeria | 57,117 | 0.1 | 1,091 |
| Senegal | 7,989 | 0.1 | 18,369 |
| Sierra Leone | 99,238 | 2.5 | 304 |
| Togo | 41,323 | 1.1 | 38,414 |

Source: Adapted by Trávníček et al. (2020) based on a survey of the Research Institute of Organic Agriculture (FiBL).
* No data for Mauritania. NA: No available data.

## 2 Materials and methods

The assessment reported here draws upon a systematic review of all documents indexed in Clarivate Analytics - Web of Science. The PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher et al. 2009) were followed. A search was performed on April 4th, 2020, using the following 'Title-Abs'-Key search query: *({organic farming} OR {organic agriculture} OR {organic food}) AND ("West* Africa" OR Sahel OR Benin OR "Burkina Faso" OR "Cape Verde" OR "Cabo Verde" OR Gambia OR Ghana OR Guinea OR "Guinea-Bissau" OR "Ivory Coast" OR "Côte d'Ivoire" OR Liberia OR Mali OR Mauritania OR Niger OR Nigeria OR Senegal OR "Sierra Leone" OR Togo)*. Three inclusion criteria were considered: geographical coverage (viz. the document deals with one or more countries in West Africa); thematic focus (viz. the main topic is organic food and farming); and document type (viz. only journal articles, book chapters or conference papers were selected; letters to editors, commentaries and/or notes were excluded). Only documents that met all the three criteria were considered eligible and included in the review.

The initial literature search yielded 1,032 documents that were published between 1990 and 2020. However, at first 90 documents were screened out based on the titles not relevant to West Africa. A further 835 documents were excluded based on the abstracts not meeting at least one of the inclusion criteria and, finally, 62 documents were excluded after the analysis of full texts. Therefore, 45 documents were included in the systematic review and underwent bibliometric and topical analyses. *Figure 1*, *Table 2* and *Table 3* summarise the selection process, the list of the selected documents, and the topics addressed in the review process.
This review was not without limitations. Indeed, the review results were affected by the search process (viz. considering only articles published in sources indexed on the Web of Science thus excluding publications in journals not indexed on Web of Science as well as the grey literature, e.g. reports) and the choice of the search terms.

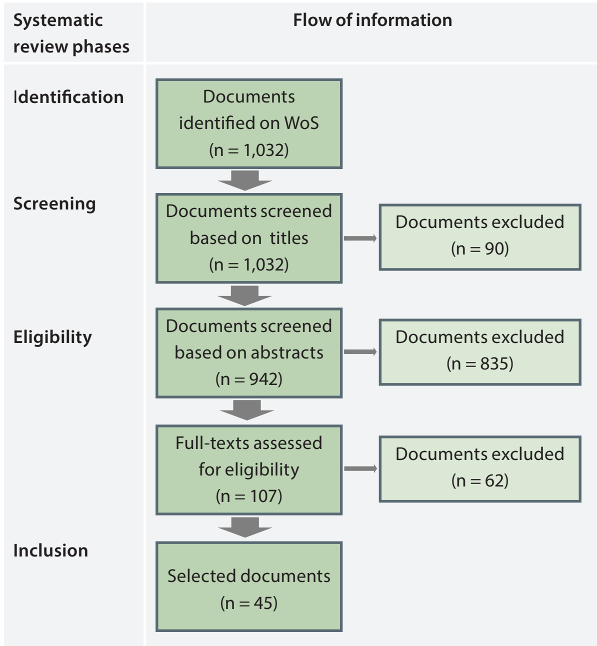


FIGURE 1
Systematic review: Articles selection process

TABLE 2
List of the selected documents

| Year | Documents number | References |
|---|---|---|
| 2020 | 1 | Avadí et al. (2020) |
| 2019 | 9 | Adebiyi et al. (2019); Amfo et al. (2019); Asigbaase et al. (2019); Babalola (2019); Bonouzin et al. (2019); de Bon et al. (2019); Emeana et al. (2019); Nicolay (2019); Ukeh et al. (2019) |
| 2018 | 3 | Andriamampianina et al. (2018); Bello and Abdulai (2018); Métouolé Méda et al. (2018) |
| 2017 | 2 | Djokoto and Afari-Sefa (2017); Van den Broeck et al. (2017) |
| 2016 | 3 | Bello and Abdulai (2016a); Bello and Abdulai (2016b); Issaka et al. (2016) |
| 2015 | 3 | Binta and Barbier (2015); Glin et al. (2015); Vidogbéna et al. (2015) |
| 2014 | 2 | Kleemann et al. (2014); Kloos and Renaud (2014) |
| 2013 | 13 | Adebayo and Oladele (2013g); Adebayo and Oladele (2013e); Adebayo and Oladele (2013a); Adebayo and Oladele (2013b); Adebayo and Oladele (2013c); Adebayo and Oladele (2013f); Adebayo and Oladele (2013d); Glin et al. (2013); Kleemann and Abdulai (2013); Onumah et al. (2013); Ouma et al. (2013); Owusu and Anifori (2013); Somé (2013) |
| 2012 | 7 | Adejuyigbe et al. (2012); Aiyelaagbe et al. (2012); Alao et al. (2012); Atungwu et al. (2012); Glin et al. (2012); Mensah et al. (2012); Probst et al. (2012) |
| 2011 | 1 | Osei et al. (2011) |
| 2010 | 1 | Probst et al. (2010) |

TABLE 3
Topics addressed in the systematic review

| Item | Description |
|---|---|
| Bibiliographical metrics and research geography | Bibliometrics: sources/journals, subject areas, authors, institutions/affiliations.<br>Research geography: West African countries considered |
| Topical focus of research on OFF in West Africa | Agriculture subsectors: crop production (and main crops addressed), animal production and fisheries |
| | Stages of the food chain (viz. production, processing, distribution/ retail/marketing, consumption) |
| | Climate change: adaptation and mitigation |
| | Environmental impacts and biodiversity conservation: biodiversity and resilience of farming systems; environmental impacts of organic farming vs. conventional farming |
| | Food security and nutrition: food security, nutrition and diets, food safety, quality of organic agro-food products |
| | Sustainable rural livelihoods: livelihoods (cf. income), women and gender, socio-economics of organic farming |
| | Barriers to and proposals for the development of organic food and farming in West Africa |

## 3 Results and discussion

### 3.1 Bibliographical metrics and research geography

The analysis of the selected documents indicates that research on organic food and farming (OFF) is rather young in West Africa. The first document that specifically deals with OFF dates back to 2010. The annual output of articles in the period 2010-2020 ranges from one (2010, 2011) to a maximum of 13 in 2013. The average *annual output* in the period 2010-2019 is less than 5 documents. The peak of the number of publications in 2013 might suggest that interest in research on organics is decreasing and/or that such research has been over the last years labelled differently (e.g. agroecology) so that it was not identified through the initial search.

As for *sources*, the analysis of the results shows that the maximum number of articles was published in the 'Journal of Food, Agriculture & Environment' (4 articles) and 'Asia Life Sciences' (3 articles). The findings of the research on OFF in West Africa were published in 38 further sources and journals. Most of the selected articles can be linked to the *research areas* of agriculture (21 out of 45 articles) followed by business economics (9 articles), environmental sciences - ecology (6 articles), food science technology (6 articles) and science technology (6 articles). The selected publications can be categorised in 17 research areas (e.g. biomedicine, anthropology, engineering, geography, sociology, entomology), which shows that OFF research draws on a range of disciplines. It can be argued that while biological and environmental sciences as well as economics are sufficiently addressed, social sciences are generally overlooked.

The bibliometric analysis shows that the most prominent, productive authors are Sijuwade Adebukola Adebayo (7 articles), Oladimeji Idowu Oladele (7 articles) and Awudu Abdulai(5 articles). The fact that 105 other authors have only one article dealing with OFF in West Africa indicates the presence of a wider range of researchers who are not especially committed to OFF as a research field. This might be due to the absence of structured research projects/programmes because of the lack of investments in research on organic farming and agro-ecology in African countries because the bulk of investments still goes to industrial, conventional agriculture (Biovision Foundation for Ecological Development and IPES-Food, 2020).

The analysis of *countries* and *affiliations* suggests that, surprisingly, the most active country in the research field is Ghana (9 articles). West African countries mentioned in affiliations also include Nigeria (6 articles), Benin (6 articles), Senegal (2 articles), Burkina Faso (1 article) and Mali (1 article). However, a large share of publications is authored by researchers based outside West Africa. These are either in Africa (e.g. South Africa, Kenya, Morocco), Europe (e.g. Germany, England, France, Netherlands, Austria, Belgium, Switzerland), North America (e.g. USA) or Oceania (e.g. Australia). This might be considered as an indicator of the weakness of the research systems in West Africa and/or lack of attention to organic food and farming in the region. Many of the prominent *institutions* in the research field are based outside West Africa. These organisations include the North West University South Africa, University of Kiel (Germany), CIRAD (France), Universite de Montpellier (France), Wageningen University and Research (Netherlands), Coventry University (UK), Michigan State University (USA), University of Natural Resources and Life Sciences (BOKU, Austria). However, many domestic organisations are active in research on OFF in Nigeria (e.g. Federal University of Agriculture Abeokuta, Michael Okpara University of Agriculture), Ghana (e.g. University of Ghana, University for Development Studies, Kwame Nkrumah University of Science and Technology), Benin (e.g. University of Abomey-Calavi, National Institute of Agricultural Research of Benin, Parakou University), and Burkina Faso (e.g. University Ouaga II).

There are large differences between West African countries in terms of research on organic food and farming. The analysis of the geography of research in the region suggests that it is mainly performed in Nigeria (18 out of 45 selected documents). This is quite normal, and somehow expected, since Nigeria is the largest and most populous country in the region. Indeed, it is essential to take into account the countries' sizes, which is often associated to their research systems (e.g. number of scientific articles per million inhabitants is used to assess country research performance). Interestingly, Ghana (12 out of 45) and Benin (6 out of 45) are also active in the research field. They are followed by Benin (6 documents), Burkina Faso (3 documents), Mali (2 documents) and Senegal (2 documents). There is no article that deals specifically with OFF in Cape Verde, Gambia, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mauritania, Niger, Sierra Leone or Togo. This suggests a lack of research activity in these countries. Furthermore, there is no single study that addresses OFF in the whole West Africa but there are some multi-country studies. For example, Andriamampianina et al. (2018) assess the capacity of organic agriculture to address food insecurity in sub-Saharan Africa with experts from Senegal, Burkina Faso and Cameroon. Meanwhile, Probst et al. (2012) investigate the marketing potential of organic vegetables in Benin, Ghana and Burkina Faso.

### 3.2 Agriculture subsectors and food chain stages

Almost all the selected documents deal with crop production whereas animal production is overlooked. The majority of papers focuses on fresh products, such as fruit (Owusu and Anifori 2013) and vegetables (Probst et al., 2010, 2012; Adebayo and Oladele, 2013c, f, d; Owusu and Anifori, 2013; de Bon et al., 2019; Amfo et al., 2019; Adebiyi et al., 2019). A number of articles deals with organic pineapple (Osei et al., 2011; Aiyelaagbe et al., 2012; Kleemann and Abdulai, 2013; Kleemann et al., 2014), mango (Ouma et al., 2013) and cocoa (Onumah et al., 2013; Glin et al., 2015; Djokoto and Afari-Sefa, 2017; Asigbaase et al., 2019). As for organic vegetables, some papers focus on specific crops such as tomato (Babalola, 2019) and cabbage (Vidogbéna et al., 2015). Apart from food crops, some articles focus on industrial crops such as cotton (Mensah et al., 2012; Glin et al., 2012; Somé, 2013; Kloos and Renaud, 2014; Métouolé Méda et al., 2018; Nicolay, 2019;

Bonou-zin et al., 2019; Avadí et al., 2020). In general, staple crops, especially grains that are destined to the domestic market, are overlooked and only a few examples such as rice (Van den Broeck et al., 2017), maize (Adejuyigbe et al., 2012), soybean (Atungwu et al., 2012) and sesame (Glin et al., 2013) are analysed. Other articles deal with organic farming in general and without focusing on any specific crop (Adebayo and Oladele, 2013b, g, e, a; Binta and Barbier, 2015; Bello and Abdulai, 2016b, a, 2018; Issaka et al., 2016; Andriamampianina et al., 2018; Ukeh et al., 2019; Emeana et al., 2019). A few articles address mixed systems; for example, Alao et al. (2012) focus on forages that are relevant for crop production and animal husbandry.

As for the *stages of the food chain*, most of the analysed literature deals with either the upstream (e.g. production) or downstream (e.g. marketing/consumption) of the food chain; intermediate stages (e.g. packing, processing) are often overlooked. As for production, the selected articles focus on soil fertility management (Alao et al., 2012; Aiyelaagbe et al., 2012; Adejuyigbe et al., 2012; Adebayo and Oladele, 2013b, a, g, e; Bonou-zin et al., 2019) or pest management (Osei et al., 2011; Mensah et al., 2012; Atungwu et al., 2012), among other topics. Articles addressing consumption deal with the attitude of consumers towards organic products and/or their willingness to pay premium prices for them (Probst et al., 2010, 2012; Owusu and Anifori, 2013; Ouma et al., 2013; Vidogbéna et al., 2015; Bello and Abdulai, 2016b, 2018; Amfo et al., 2019). Some articles take a holistic approach in dealing with organic food and farming. For example, papers that analyse certification (Kleemann and Abdulai, 2013; Kleemann et al., 2014) often address production rules as well as access to market and communication with consumers. Similarly, papers that adopt a life-cycle assessment approach analyse different stages. For instance, Avadí et al. (2020) assess the environmental impacts of Malian cotton during the agricultural and the ginning (cf. post-harvest processing) phases.

## 3.3 Topical analysis

### 3.3.1 Climate change

The analysed literature suggests that organic agriculture can mitigate the effect of climate change in West Africa. Avadí et al. (2020) argue that Malian organic cotton products are similar to literature values in terms of greenhouse gas (GHG) emissions. Bonou-zin et al. (2019) found that organic cotton causes less GHG emission than conventional cotton in Northern Benin. Likewise, Binta and Barbier (2015) show that carbon emissions are lower in organic horticultural farms than in conventional ones in Senegal (Niayes region). This indicates that increasing organic farming can be regarded as a GHG mitigation measure.

Organic agriculture is also considered to support adaptation to climate change. For instance, Kloos and Renaud (2014) found that organic cotton production reduced the risks of extreme climate events thus contributing to the reduction of economic risks at household level in Benin. However, Adebiyi et al. (2019) pointed out that the perceived vulnerability to the yield and financial losses from heavy precipitation hindered the adoption of organic farming in Nigeria.

### 3.3.2 Environmental impacts and biodiversity

Some papers analyse the relationship between organic farms and the conservation of *biodiversity*. Asigbaase et al. (2019) show that organic cocoa farms conserve more native floristic diversity when compared with conventional farms in the Eastern Region of Ghana. Adebayo and Oladele (2013d) show that vegetable farmers in South Western Nigeria believe that organic farming improves soil structure and fertility as well as its biological activity.

Other papers highlight the lower *environmental impacts* of organic farms compared to conventional ones. Following their life-cycle assessment (LCA) of conventional and organic cotton in Mali, Avadí et al. (2020) suggest that despite comparatively lower yields, organic cotton products feature lower impacts than conventional ones due to lower input intensity. The main drivers of environmental impacts for organic cotton are organic fertilisers and natural pesticides (Avadí et al., 2020). However, Bonou-zin et al. (2019) show that "although organic cotton producers contribute less to GHG emission, they are environmentally inefficient compared to their conventional counterparts" (p. 14) in the cotton belt of Northern Benin. This clearly shows that the comparative performance of organic farming is site-specific and depends on the practices used in organic and conventional farms in each context.

### 3.3.3 Food security, food safety and nutrition

It is widely believed that *productivity* is lower in organic farming, which might have negative implications in terms of *food security*. For example, de Bon et al. (2019) report that cabbage and tomato yields are lower in organic farms. Likewise, the elicitation of expert knowledge carried out by Andriamampianina et al. (2018) suggests that "the yields of organic systems are about 41 % lower than the yields of conventional systems" in sub-Saharan Africa. However, de Bon et al. (2019) note that organic yields are sometimes higher than conventional ones among vegetable producers in Senegal. Beyond yields, Issaka et al. (2016) suggest that organic farming has the potential to achieve a higher increase in total factor productivity in Northern Ghana compared with conventional agriculture.

*Food safety* is one of the determinants of the consumption of organic foods. Organic products are perceived by consumers as being safer (Amfo et al., 2019). Williamson et al. (2008) showed that there is a contrast between the increasing attention to food safety and pesticide restrictions in export horticulture to Europe and food crops grown for domestic markets. Amfo et al. (2019) show that food safety consciousness affects organic vegetables expenditure and consumption in Tamale (Ghana). Meanwhile, Owusu and Anifori (2013) pointed out that, beside socioeconomic characteristics, product cleanness and freshness have a positive effect on the willingness of consumers to pay a premium for organic watermelon in urban Kumasi (Ghana). Likewise, Probst et al. (2010) found that attributes such as freshness and healthy appearance were central to vegetable choices in

Kumasi and Accra (Ghana), although consumers were mostly unaware of agro-chemical risks.

### 3.3.4 Livelihoods

It is widely acknowledged that organic agriculture can increase the income and improve the livelihoods of farming households and rural communities in developing countries, such as those of West Africa. Indeed, premium prices may increase the income of small-scale farmers. In this respect, an elicitation of the knowledge of experts in Burkina Faso, Senegal and Cameroon (Andriamampianina et al., 2018) shows that **"the prices of organic products are 34% higher than prices of products from conventional agriculture"**. Kleemann et al. (2014) conclude that organic-certified pineapple yields a significantly higher return on investment (ROI) than GlobalGAP-certified pineapple in Ghana, mainly due to the price premium. Similarly, Kleemann and Abdulai (2013) found that there is a positive relationship between the intensity of the use/adoption of agro-ecological practices and ROI among pineapple producers in Ghana. Moreover, the use of organic amendments is cheaper than synthetic agrochemicals in West African countries (Osei et al. 2011), which affects positively the farm gross margin and, consequently, farmer's income. In this context, Adebayo and Oladele (2013d) argue that organic agriculture holds a great potential for effectively contributing to local food security and increased family health at low cost compared to conventional agriculture. Using gross margin as economic indicator, Binta and Barbier (2015) suggest that organic agriculture is more attractive for horticultural producers in the Niayes region (Senegal) only where premium prices are available. Kloos and Renaud (2014) argue that organic agriculture supports sustainable livelihoods even in the context of changing climate. However, the high cost of certification may negatively affect the adoption and ROI of certified organic farming (Kleemann et al., 2014). Furthermore, organic certification and, consequent, premium prices may limit the affordability of organic products (Probst et al., 2010).

Organic agriculture can contribute to the empowerment of different socio-economic groups such as youth and women (Somé, 2013; Kloos and Renaud, 2014). Adebiyi et al. (2019) conclude that *gender* is one of the variables that shape the adoption of organic horticulture (e.g. leafy vegetables) in Ibadan (Oyo State, Nigeria). Many authors consider gender as a factor that affects the adoption of organic agriculture practices such as minimum tillage (Adebayo and Oladele, 2013b) and crop rotation and intercropping (Adebayo and Oladele, 2013a) in Nigeria. The literature also suggests that the attitude towards OFF is influenced by gender. For example, Vidogbéna et al. (2015) show that women in southern Benin pay more attention to the safety of products so that they are more likely to pay premium prices for organic products.

### 3.3.5 Barriers to and proposals for the development of organic farming in West Africa

Different factors hinder the development of organic food and farming in West Africa. These relate, among others, to agricultural policy, agronomic research, institutional environment and extension management.

It seems that one of the weaknesses of OFF is that it relies on support from a wide range of stakeholders and institutions. In fact, Nicolay (2019) suggests that organic farming "depends much more on societal support for extension, technology development and policy coherence than commercial farms" (p. 86). In this context, extension and advisory services can play a central role in the agro-ecological transition towards organic farming (Adebayo and Oladele, 2013d; Métouolé Méda et al., 2018; Emeana et al., 2019) as they are important sources of information on organic farming in West Africa. Indeed, Adebayo and Oladele (2013c) show that extension agents represent a chief source of information for organic vegetable producers in southwest Nigeria. Emeana et al. (2019) stress that factors such as research and extension management impede organic farming transition in Nigeria and call for an ambitious organic agriculture policy that supports organic agricultural research and information dissemination to farmers by extension services. Also, Issaka et al. (2016) argue that the major constraints confronting organic farmers relate to access to extension and farm inputs. Kloos and Renaud (2014) report the insufficient availability of organic material as one of the obstacles to the development of organic farming among cotton farmers in Benin. Likewise, Adebiyi et al. (2019) point out that the lack of financial resources to hire labour or access organic inputs constrains the adoption of organic farming in Nigeria. Organic producers face many technical problems and that might explain why Onumah et al. (2013) conclude that the organic cocoa production system is less technically efficient than the conventional system in Ghana. Indeed, the Ghanaian organic cocoa sector is young and needs a lot of education so that farmers become familiar with the new practices to bridge the gap with conventional cocoa producers.

Many scholars stress the importance of the *education* of both consumers and producers for the development of organic farming and organic food market in West Africa (Métouolé Méda et al., 2018; Ukeh et al., 2019; Bonou-zin et al., 2019). Adebiyi et al. (2019) suggest that "exposing farmers to information about the economic viability of organic farming, the potential health effects of chemical pesticides and herbicides, and to the knowledge of organic pest and soil fertility management can motivate adoption" (p. 16) of organic production in Nigeria. Bonou-zin et al. (2019) argue that there is a need for more technical support and education to improve the environmental efficiency of organic cotton in Benin. There is also a need to raise the awareness of extension agents and improve their attitude towards organic farming. For that, Adebayo and Oladele (2013d) recommend that extension agents' training should include more messages on organic agriculture techniques.

Some authors call for paying more attention to organic food and farming in agricultural policies (Probst et al., 2012; Emeana et al., 2019). Probst et al. (2012) argue that market mechanisms and processes are not enough to develop organic farming in West Africa so that public commitment is vital to facilitate the change towards organic food and farming. Some papers also stress the need to improve the governance of the whole organics sector, as institutional factors affect the adoption of organic farming (Glin et al., 2012; Métouolé Méda et al., 2018; Adebiyi et al., 2019). For instance, Adebiyi et al. (2019) suggest that institutional environment affects the adoption of organic horticulture (e.g. leafy vegetables) in Nigeria. Nicolay (2019) puts forward the view that organic agriculture is nested in socio-economic and political networks, which makes its development challenging particularly for countries with poorly developed institutions and weak organisations. Glin et al. (2015) found that the Organic Cocoa Network in Ghana is moving towards hybrid governance arrangements in which the state, which is still a major player, is involved along with NGO networks and businesses. It is evident from the analysed literature that NGOs have been playing a prominent role in the development of organic farming in West Africa (Glin et al., 2012).

## 4 Conclusions

The paper reviews in a comprehensive way research on organic food and farming (OFF) in West Africa published in sources indexed in the Web of Science. The study concludes that OFF is relatively young in West Africa and there is a huge research gap in the region in general and in Cape Verde, Gambia, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mauritania, Niger, Sierra Leone and Togo in particular. Indeed, only Ghana, Nigeria and Benin have done few research studies on OFF. Most of the research outputs are authored by researchers outside West Africa. There is also a lack of regional and cross-country studies. The review shows clearly the potentials and prospects of organic agriculture in West Africa as well as factors limiting its adoption. Factors hindering the development of OFF in West Africa relate, among others, to agricultural policy, agronomic research, institutional environment and extension management. The study, therefore, recommends that awareness of OFF should be raised, organic farmers supported, and research and extension on OFF strengthened in West Africa. It is paramount to raise awareness about the multiple and multifaceted environmental (e.g. climate change mitigation and adaptation, biodiversity conservation, sustainable soil management, reduction of chemicals use) and socio-economic (e.g. products quality and safety, consumer health, poverty eradication, gender empowerment) benefits of organic farming. The paper also stresses the need to improve the governance of the whole organic agriculture sector. There is also a need for an ambitious organic agriculture policy that supports organic agricultural research and information dissemination to farmers by extension services.

## Acknowledgements

This work was carried out within the project SUSTLIVES (SUSTaining and improving local crop patrimony in Burkina Faso and Niger for better LIVes and EcoSystems) of the DeSIRA initiative (Development Smart Innovation through Research in Agriculture) financed by the European Union.

## REFERENCES

Adebayo SA, Oladele OI (2013a) Factors affecting adoption intensity of organic agricultural practices in southwest Nigeria: Crop rotation and intercropping. Asia Life Sci, 345–353

Adebayo SA, Oladele OI (2013b) Factors affecting adoption intensity of organic agricultural practices in southwest Nigeria: Minimum tillage and fire. Asia Life Sci, 149–156

Adebayo SA, Oladele OI (2013c) Information-seeking behavior of organic vegetable farmers in southwest Nigeria. Asia Life Sci, 367–378

Adebayo SA, Oladele OI (2013d) Vegetable farmers' attitude towards organic agriculture practices in South Western Nigeria. J Food Agric Environ 11(2):548–552

Adebayo SA, Oladele OI (2013e) Factors affecting adoption intensity of organic agricultural practices in South West Nigeria: Green manure and cover crop. J Food Agric Environ 11(2):687–690

Adebayo Adebayo SA, Oladele OI (2013f) Socio-economic status of organic vegetable farmers in South West Nigeria. J Food Agric Environ 11(2):397–402

Adebayo SA, Oladele OI (2013g) Adoption of organic farming practices in South Western Nigeria. J Food, Agric Environ 11(2):403–410

Adebiyi JA, Olabisi LS, Richardson R, Liverpool-Tasie LSO, Delate K (2019) Drivers and Constraints to the Adoption of Organic Leafy Vegetable Production in Nigeria: A Livelihood Approach. Sustainability 12:96, doi:10.3390/su12010096

Adejuyigbe CO, Adesodun JK, Harris PJC, Aiyelaagbe IOO (2012) Potential of on-farm produced compost and organic amendments in soil fertility management for organic maize production in southwestern Nigeria. Arch Agron Soil Sci 58:S170–S174, doi:10.1080/03650340.2012.696776

Aiyelaagbe IOO, Oshuniyi AA, Adegoke JO (2012) Response of "Smooth Cayenne" Pineapple to Organic Fertilizer in South Western Nigeria. Acta Hortic 933:261–264, doi:10.17660/ActaHortic.2012.933.32

Alao OJ, Aniwe DP, Moses AO (2012) Effects of animal manure and harvest interval on the growth, dry matter yield and nutritive quality of three grasses at Abeokuta, Southwest Nigeria. In: Rahmann G, Godinho D (eds) 2nd Organic Animal Husbandry Conference on Tackling the Future Challenges of Organic Animal Husbandry; Sep. 12-14, 2012; Hamburg, Germany. Johann Heinrich von Thuenen Institute, Braunschweig, Germany, pp 83–87

Amfo B, Ansah IGK, Donkoh SA (2019) The effects of income and food safety perception on vegetable expenditure in the Tamale Metropolis, Ghana. J Agribus Dev Emerg Econ 9:276–293, doi:10.1108/JADEE-07-2018-0088

Andriamampianina L, Temple L, de Bon H, Malézieux E, Makowski D (2018) Évaluation pluri-critères de l'agriculture biologique en Afrique subsaharienne par élicitation probabiliste des connaissances d'experts. Cah Agric 27:45002, doi:10.1051/cagri/2018030

Asigbaase M, Sjogersten S, Lomax BH, Dawoe E (2019) Tree diversity and its ecological importance value in organic and conventional cocoa agroforests in Ghana. PLoS One 14:e0210557, doi:10.1371/journal.pone.0210557

Atungwu J, Lawal O, Afolami S, Adejuyigbe C (2012) Appraisal of composts for suppression of Meloidogyne species and enrichment of micro-arthropods in soybean fields. Biol Agric Hortic 28:101–110, doi:10.1080/01448765.2012.681348

Avadí A, Marcin M, Biard Y, Renou A, Gourlot JP, Basset-Mens C (2020) Life cycle assessment of organic and conventional non-Bt cotton products from Mali. Int J Life Cycle Assess 25:678–697, doi:10.1007/s11367-020-01731-x

Babalola OA (2019) Assessment of the contribution of microbial activities to tomato growth and yield under an organic production system. Open Agric 4:661–675, doi:10.1515/opag-2019-0063

Bello M, Abdulai A (2018) The use of a hybrid latent class approach to identify consumer segments and market potential for organic products in Nigeria. Agribusiness 34:190–203, doi:10.1002/agr.21506

Bello M, Abdulai A (2016a) Impact of Ex-Ante Hypothetical Bias Mitigation Methods on Attribute Non-Attendance in Choice Experiments. Am J Agric Econ 98:1486–1506, doi:10.1093/ajae/aav098

Bello M, Abdulai A (2016b) Measuring heterogeneity, survey engagement and response quality in preferences for organic products in Nigeria.

Appl Econ 48:1159–1171, doi:10.1080/00036846.2015.1093089
Bengtsson J, Ahnström J, Weibull AC (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J Appl Ecol 42:261–269, doi:10.1111/j.1365-2664.2005.01005.x
Binta BAA, Barbier B (2015) Economic and environmental performances of organic farming system compared to conventional farming system: A case study of the horticulture sector in the Niayes Region of Senegal. Procedia Environ Sci 29:17–19, doi:10.1016/j.proenv.2015.07.132
Biovision Foundation for Ecological Development, IPES-Food (2020) Money Flows: What is holding back investment in agroecological research for Africa? Zürich.
Bliss K, Padel S, Cullen B, Ducottet C, Mullender S, Rasmussen IK, Moeskops B (2019) Exchanging knowledge to improve organic arable farming: an evaluation of knowledge exchange tools with farmer groups across Europe. Org Agric 9:383–398, doi:10.1007/s13165-018-0238-6
Bonou-zin RDC, Allali K, Fadlaoui A (2019) Environmental efficiency of organic and conventional cotton in Benin. Sustainability 11:3044, doi:10.3390/su11113044
de Bon H, Brun-Diallo L, Sène J-M, et al (2019) Rendements et pratiques des cultures maraîchères en agriculture biologique au Sénégal. Cah Agric 28:2, doi:10.1051/cagri/2019001
De Bon H, Temple L, Malézieux E, Bendjebbar P, Fouilleux E, Silvie P (2018) Organic agriculture in Africa: A source of innovation for agricultural development. Perspective 48:1–4, doi:10.19182/agritrop/00036
de Ponti T, Rijk B, van Ittersum MK (2012) The crop yield gap between organic and conventional agriculture. Agric Syst 108:1–9, doi:10.1016/j.agsy.2011.12.004
de Porras Acuna MA, Niggli U, Love N, Moeskops B, Padel S, Schmutz U, Lehejček J, Beck A, Müller A, Ulmer K, et al. (2018) Scientific evidence on how organic food and farming contributes to sustainable food security. TP Organics Research Briefing. Brussels
de Schaetzen S (2019) Organic agriculture and the sustainable development goals - part of the solution. Waddinxveen, Netherlands, 68 p
Djokoto JG, Afari-Sefa V (2017) Alternative functional forms for technology choice: Application to cocoa production technologies. Technol Soc 50:110–120, doi:10.1016/j.techsoc.2017.06.001
Emeana EM, Trenchard L, Dehnen-Schmutz K, Shaikh S (2019) Evaluating the role of public agricultural extension and advisory services in promoting agro-ecology transition in Southeast Nigeria. Agroecol Sustain Food Syst 43:123–144, doi:10.1080/21683565.2018.1509410
Gabriel D, Sait SM, Kunin WE, Benton TG (2013) Food production vs. biodiversity: comparing organic and conventional agriculture. J Appl Ecol 50:355–364, doi:10.1111/1365-2664.12035
Gama J, Amudav D (2020) Latest Developments in Organic Agriculture in Africa. In: Willer H, Schlatter B, Trávníček J, et al. (eds) The world of organic agriculture. Statistics and emerging trends 2020. Research Institute of Organic Agriculture (FiBL) & IFOAM – Organics International, Frick & Bonn, pp 186–192.
Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, Buchmann N, Maeder P, Stolze M, Smith P, El-Hage Scialabba N, Niggli U (2012) Enhanced top soil carbon stocks under organic farming. Proc Natl Acad Sci 109:18226–18231, doi:10.1073/pnas.1209429109
Glin LC, Mol APJ, Oosterveer P (2013) Conventionalization of the organic sesame network from Burkina Faso: shrinking into mainstream. Agric Human Values 30:539–554, doi:10.1007/s10460-013-9435-9
Glin LC, Mol APJ, Oosterveer P, Vodouhê SD (2012) Governing the transnational organic cotton network from Benin. Glob Networks 12:333–354, doi:10.1111/j.1471-0374.2011.00340.x
Glin LC, Oosterveer P, Mol APJ (2015) Governing the Organic Cocoa Network from Ghana: Towards hybrid governance arrangements? J Agrar Chang 15:43–64, doi:10.1111/joac.12059
Gomiero T, Pimentel D, Paoletti MG (2011) Environmental impact of different agricultural management practices: Conventional vs. organic agriculture. CRC Crit Rev Plant Sci 30:95–124, doi:10.1080/07352689.2011.554355
Hammas MA, Ahlem Z (2017) Organic Farming: A path of sustainable development. Int J Econ Manag Sci 06:1–7, doi:10.4172/2162-6359.1000456
Helm D (2019) Green and prosperous land: A blueprint for rescuing the British countryside. William Collins, London.
Hsu SY, Chang CC, Lin TT (2016) An analysis of purchase intentions toward organic food on health consciousness and food safety with/under structural equation modeling. Br Food J 118:200–216, doi:10.1108/BFJ-11-2014-0376
IFAD (2016) Rural Development Report 2016: Fostering inclusive rural transformation. International Fund for Agricultural Development (IFAD). Rome.
Issaka Y, Antwi M, Tawia G (2016) A Comparative analysis of productivity among organic and non-organic farms in the West Mamprusi District of Ghana. Agriculture 6:13, doi:10.3390/agriculture6020013
Jouzi Z, Azadi H, Taheri F, et al (2017) Organic farming and small-scale farmers: Main opportunities and challenges. Ecol Econ 132:144–154, doi:10.1016/j.ecolecon.2016.10.016
Kilcher L (2007) How organic agriculture contributes to sustainable development. J Agric Res Trop Subtrop 89:31–49.
Kleemann L, Abdulai A (2013) Organic certification, agro-ecological practices and return on investment: Evidence from pineapple producers in Ghana. Ecol Econ 93:330–341, doi:10.1016/j.ecolecon.2013.06.017
Kleemann L, Abdulai A, Buss M (2014) Certification and access to export markets: Adoption and return on investment of organic-certified pineapple farming in Ghana. World Dev 64:79–92, doi:10.1016/j.worlddev.2014.05.005
Kloos J, Renaud FG (2014) Organic cotton production as an adaptation option in North-West Benin. Outlook Agric 43:91–100, doi:10.5367/oa.2014.0166
Kluger J (2010) What's So great about organic food? Time 176:30–32.
Lori M, Symnaczik S, Maeder P, De Deyn G, Gattinger A (2017) Organic farming enhances soil microbial abundance and activity–A meta-analysis and meta-regression. PLoS One 12:e0180442, doi:10.1371/journal.pone.0180442
Maeder P, Fliessbach A, Dubois D, Gunst L, Fried P, Niggli U (2002) Soil fertility and biodiversity in organic farming. Science (80) 296:1694–1697, doi:10.1126/science.1071148
Mensah RK, Vodouhe DS, Sanfillippo D, Assogba G, Monday P (2012) Increasing organic cotton production in Benin West Africa with a supplementary food spray product to manage pests and beneficial insects. Int J Pest Manag 58:53–64, doi:10.1080/09670874.2011.645905
Métouolé Méda YJ, Egyir IS, Zahonogo P, Donsaananang Jatoe JB, Atewamba C (2018) Institutional factors and farmers' adoption of conventional, organic and genetically modified cotton in Burkina Faso. Int J Agric Sustain 16:40–53, doi:10.1080/14735903.2018.1429523
Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. PLoS Med 6:e1000097, doi:10.1371/journal.pmed.1000097
Muller A, Schader C, El-Hage Scialabba N, Brueggemann J, Isensee A, Erb KH, Smith P, Klocke P, Leiber F, Stolze M, Niggli U (2017) Strategies for feeding the world more sustainably with organic agriculture. Nat Commun 8:1290, doi:10.1038/s41467-017-01410-w
Nicolay GL (2019) Understanding and Changing Farming, Food & Fiber Systems. The organic cotton case in Mali and West Africa. Open Agric 4:86–97, doi:10.1515/opag-2019-0008
Niggli U (2015) Sustainability of organic food production: challenges and innovations. Proc Nutr Soc 74:83–88, doi:10.1017/S0029665114001438
Onumah JA, Onumah EE, Al-Hassan RM, Brümmer B (2013) Meta-frontier analysis of organic and conventional cocoa production in Ghana. Agric Econ–Czech 59:271–280, doi:10.17221/128/2012-AGRICECON
Osei K, Agyemang A, Asante JS, Moss R, Nafeo A (2011) Nematode suppression and yield improvement potential of organic amendments in pineapple production. Acta Hortic 367–371, doi:10.17660/ActaHortic.2011.902.42
Ouma S, Boeckler M, Lindner P (2013) Extending the margins of marketization. Geoforum 48:225–235, doi:10.1016/j.geoforum.2012.01.011
Owusu V, Anifori MO (2013) Consumer willingness to pay a premium for organic fruit and vegetable in Ghana. Int Food Agribus Manag Rev 16:67–86, doi:10.22004/ag.econ.144649
Ponisio LC, M'Gonigle LK, Mace KC, Palomino J, de Valpine P, Kremen C (2015) Diversification practices reduce organic to conventional yield gap. Proc R Soc B Biol Sci 282:1–7, doi:10.1098/rspb.2014.1396
Probst L, Aigelsperger L, Hauser M (2010) Consumer attitudes towards vegetable attributes: potential buyers of pesticide-free vegetables in Accra and Kumasi, Ghana. Ecol Food Nutr 49:228–245, doi:10.1080/03670241003766055

Probst L, Houedjofonon E, Ayerakwa HM, Haas R (2012) Will they buy it? The potential for marketing organic vegetables in the food vending sector to strengthen vegetable safety: A choice experiment study in three West African cities. Food Policy 37:296–308, doi:10.1016/j.foodpol.2012.02.014

Qiao Y, Martin F, Cook S, He X, Halberg N, Scott S, Pan X (2018) Certified Organic Agriculture as an Alternative Livelihood Strategy for Small-scale Farmers in China: A Case Study in Wanzai County, Jiangxi Province. Ecol Econ 145:301–307, doi:10.1016/j.ecolecon.2017.10.025

Reganold JP, Wachter JM (2016) Organic agriculture in the twenty-first century. Nat Plants 2:15221, doi:10.1038/nplants.2015.221

Robertson G, Gross KL, Hamilton SK, Landis DA, Schmidt TM, Snapp SS, Swinton SM (2014) Farming for ecosystem services: An ecological approach to production agriculture. Bioscience 64:404–415, doi:10.1093/biosci/biu037

Sandhu HS, Wratten SD, Cullen R (2010) Organic agriculture and ecosystem services. Environ Sci Policy 13:1–7, doi:10.1016/j.envsci.2009.11.002

Scialabba NE-H, Müller-Lindenlauf M (2010) Organic agriculture and climate change. Renew Agric Food Syst 25:158–169, doi:10.1017/S1742170510000116

Setboonsarng S, Gregorio EE (2017) Achieving sustainable development goals through organic agriculture: Empowering poor women to build the future [online]. Asian Development Bank, Manila. Retrieved from <http://dx.doi.org/10.22617/WPS179123-2> [at 02 Dec 2020]

Seufert V (2012) Organic Agriculture as an opportunity for sustainable agricultural development [online]. Institute for the Study of International Development, Montreal, Research to Practice Policy Briefs, PB-2012-13. Retrieved from <https://www.mcgill.ca/isid/files/isid/pb_2012_13_seufert.pdf> [at 03 Dec 2020]

Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485:229–232, doi:10.1038/nature11069

Seufert V, Ramankutty N, Mayerhofer T (2017) What is this thing called organic? – How organic farming is codified in regulations. Food Policy 68:10–20, doi:10.1016/j.foodpol.2016.12.009

Smith A (2010) Africa's growing role in world trade could provide opportunities. Acta Hortic 879:123–127, doi:10.17660/ActaHortic.2010.879.10

Somé B (2013) "Hot money": Gender and the politics of negotiation and control over income in West African smallholder households. Africa (Lond) 83:251–269, doi:10.1017/S000197201300003X

Trávníček J, Schlatter B, Lernoud J, Willer H (2020) Africa: Current Statistics. In: Willer H, Schlatter B, Trávníček J, et al. (eds) The world of organic agriculture. Statistics and emerging trends 2020. Research Institute of Organic Agriculture (FiBL) and IFOAM – Organics International, Frick & Bonn, pp 193–200

Tsiafouli MA, Thébault E, Sgardelis SP, de Ruiter PC, van der Putten WH, Birkhofer K, Hemerik L, de Vries FT, Bardgett RD, Brady MV, et al.(2015) Intensive agriculture reduces soil biodiversity across Europe. Glob Chang Biol 21:973–985, doi:10.1111/gcb.12752

Tuomisto HL, Hodge ID, Riordan P, Macdonald DW (2012) Does organic farming reduce environmental impacts? – A meta-analysis of European research. J Environ Manage 112:309–320, doi:10.1016/j.jenvman.2012.08.018

Ukeh OO, Ozoemelam OR, Justina EC, Nduka OOD (2019) Beyond just branding gimmick: Power of youths in eco-certification in Abia State, Nigeria. Mark Manag Innov 69–81, doi:10.21272/mmi.2019.4-06

UNCTAD, UNEP (2008) Organic agriculture and food security in Africa. New York and Geneva.

Van den Broeck G, Vlaeminck P, Raymaekers K, Vande Velde K, Vranken L, Maertens M (2017) Rice farmers' preferences for fairtrade contracting in Benin: Evidence from a discrete choice experiment. J Clean Prod 165:846–854, doi:10.1016/j.jclepro.2017.07.128

Vidogbéna F, Adégbidi A, Tossou R, Assogba-Komlan F, Martin T, Ngouajio M, Simon S, Parrot L, Zander KK (2015) Consumers' willingness to pay for cabbage with minimized pesticide residues in Southern Benin. Environments 2:449–470, doi:10.3390/environments2040449

Willer H, Lernoud J (eds) (2020) The world of organic agriculture statistics and emerging trends 2020. Frick and Bonn.

Williamson S, Ball A, Pretty J (2008) Trends in pesticide use and drivers for safer pest management in four African countries. Crop Prot 27:1327–1334, doi:10.1016/j.cropro.2008.04.006

Zwierzchowski G, Ametaj BN (2018) Minerals and heavy metals in the whole raw milk of dairy cows from different management systems and sountries of origin: A meta-analytical study. J Agric Food Chem 66(26):6877–6888, doi:10.1021/acs.jafc.8b00904

POSITION PAPER

# Policies for agroecology in Europe, building on experiences in France, Germany and the United Kingdom

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Received: June 9, 2020
Revised: January 7, 2021
Accepted: January 12, 2021


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KEYWORDS **agricultural policy, agroecology, organic farming, CAP reform, Europe**

## 1 Introduction

Agroecology, first conceptualised in the mid-1920s, has recently been attracting increasing interest as an alternative to more industrialised forms of agriculture. However, there is a lack of consistency in definitions of agroecology, ranging from an academic discipline to a movement for the socio-economic as well as ecological transformation of agriculture. There is also a lack of clarity as to its relationship with other alternative agricultural approaches that have many principles in common, such as conservation agriculture and organic farming. This conceptual fluidity creates tensions in debates, but also makes agroecology attractive to policy makers and scientists who may be less comfortable with more rigidly defined approaches.

In this position paper, we explore some of the underlying issues and tensions, to see if it is possible to reach a common conceptualisation that can serve as basis for policy making. The authors have several decades of research experience in the development of organic farming and agroecology, and their integration into agricultural policy, both in their home countries and at the European level. Building on this, we explore how policy needs might be addressed within current proposed and planned European and national policy frameworks, with a focus primarily on the situation in France, Germany and the United Kingdom.

The choice of the three case studies reflects the knowledge and experience of the authors, as well as contrasting approaches to policy, with France recently promoting agroecology as such (Wezel and David, 2020), Germany strongly focused on organic farming, and the United Kingdom engaging with both on a more limited basis. A comparative analysis of agroecology in France and Germany has previously been undertaken by Wezel et al. (2009), although the policy and research landscape in both countries has changed since then. Policies for agroecology in the United Kingdom and France have previously been compared by Ajates Gonzalez et al. (2018). These three countries have also recorded the highest number of research publications on agroecology in a European context (Ollivier and Bellon, 2021).

Building on the case studies, this paper provides an updated, comparative analysis of the status of agroecology in the frame of agricultural policy in Europe. It is divided into three parts: first, it identifies multiple challenges regarding the concept of agroecology itself, including multiple and competing understandings of the concept. Second, it traces

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recent policy changes in the three case study counties and asks what these mean for agroecology in Europe. Thirdly, it makes a number of recommendations on what the status quo means for future agroecology policies and transformative potential, including mentioning new policies and their potential impact.

## 2 Development of agroecology – concepts and practice

### 2.1 Definitions of agroecology

Agroecology has come a long way since it was coined as an academic term almost a century ago (e.g. Azzi, 1928). It now crosses a variety of social contexts (Wezel et al., 2009), while being internationalised and institutionalised (Doré and Bellon, 2019), and used by FAO, IFOAM and dedicated professional associations, including Agroecology Europe[3]. Legal and political frameworks for agroecology now exist in several countries, in particular Central and Latin America and the Caribbean, whereas in Europe only France has a specific policy programme.

The debate around agroecology is influenced by a number of contrasting definitions (Lampkin et al., 2015; Loconto and Fouilleux, 2019). From an academic perspective, the term can be interpreted as a research discipline, with a focus on the ecology of agricultural systems considered as agroecosystems. From a practitioner perspective, it can be interpreted in a more applied sense as the application of ecological principles and processes to the design and management of agricultural systems (agroecosystem management). But it can also be interpreted in the context of a social movement, including the transformation of socio-economic as well as technical processes in agricultural and food systems. For some, the transformative social movement definition may be seen as a strong vision, with the more agronomic focus seen as a weak vision (López-i-Gelats et al., 2016). HLPE (2019) and Wezel et al. (2020) identify a consolidated set of 13 related agroecological principles and recognise the diversity of actors (scientists, practitioners) and social activities involved in the transformation of food and farming systems. For the purposes of this paper, with its focus on policy perspectives, we have adopted this broader definition of the term.

### 2.2 Historical development of agroecology perspectives

From an academic perspective, three main periods in the development of agroecology can be identified:

1. The first period (1920–1970) is that of pioneers rooted in the scientific world (e.g. Azzi (1928) and Bensin (1940), with a focus on ecology applied to agriculture and the science of soil conservation; and Tischler (1965), with a focus on the biological regulation of pests). These researchers were relatively isolated and with limited audience despite their international perspective and their enrolment in various institutions.

2. The following period (1970–1990), from which the Californian (Gliessman, 2015), Latin American (Altieri, 1987) and Andalusian (Sevilla Guzman and Woodgate, 1997) currents of agroecology emerged, began with a social and political orientation together with its inclusion in dedicated curricula (Nicot et al., 2018) and a broader focus on the entire food system (Francis et al., 2003).

3. Finally, since the mid-1990s, agroecology has changed, in particular with the inception of numerous dedicated scientific institutions that produce an increasingly large and diversified volume of work (Ollivier and Bellon, 2021). However, its development is highly differentiated from one country to another, both in terms of interpretation and in the social areas where the concept is deployed. Flexibility in interpretation also allows agroecological approaches to develop in locally adapted patterns.

This historical development of the concept also illustrates the different conceptual definitions of the term, from agroecology as an academic discipline, to an agroecosystem management approach to farming and, more recently, a focal point for the development of a transnational coalition of actors promoting radically different agricultural and food systems, that involve a transformative approach also in the socio-economic arena.

As we explore further in this paper, these developments were not unique, but often parallel and intertwined with debates about other agricultural alternatives, including integrated pest management, conservation agriculture, organic farming, bio-dynamic agriculture, regenerative agriculture, agroforestry and permaculture. These have all developed over similar time-scales since the early 1900s as responses to the same challenges (e.g. dust bowls and soil conservation, pesticides and biodiversity conservation, global warming, animal welfare and social justice issues in food systems) and share many common perspectives. The development of agroecology also displays common features with the three-stage trajectory of the organic movement: first with pioneers, then with institutionalisation, and currently with the broadening of organic food and farming to address a wider range of challenges alongside other alternative agricultural approaches.

At the same time, the development of the concept and the emergence of a coalition of actors should not, however, mask the existence of tensions around agroecology, as illustrated for example by Ajates Gonzalez et al. (2018). Even if it is already old, its meaning is the object of a continuous work of redefinition, particularly during its implementation in politics. We are thus witnessing, in different contexts, dynamics of appropriation, re-signification (Rivera-Ferre, 2018) or re-differentiation of the actors around the concept.

In the next sections we examine the development of agroecology and its policy relevance in three European countries, in order to understand how some of these tensions within agroecology, and between agroecology and external interests, have been addressed.

### 2.3 Development of a national policy for agroecology in France

In policy terms, France has taken a lead in the development of agroecology, both nationally and internationally, including as the lead sponsor of the first FAO Agroecology Symposium in Rome in 2014. Between 2012 and 2017, the socialist

3 https://www.agroecology-europe.org

Minister of Agriculture Stéphane le Foll, steadily pursued a public policy aimed at significantly changing the way agricultural production is carried out in France. The "Produire autrement" (produce otherwise) plan (MAAF, 2014a), launched in June 2012, carried the "agro-ecology" banner. Its main thrust was to organise collective changes in farmers' practices that would combine economic profitability and environmental performance. Social aspects were added later. The use of "agro-ecology" by the Minister was partly opportunistic, influenced by two professional agricultural groups that both use the term: that of ecologically intensive agriculture (Griffon 2014), and that of conservation agriculture (no-till techniques with permanent soil cover and crop diversification); overlooking the fact that social movements had previously used the term (Bellon and Ollivier 2012; Bellon and Ollivier 2018). France's national research institute, INRAE, designed a research agenda on agroecology in 2010, as well as other research institutions (e.g. CIRAD) (Caquet et al., 2020; Soussana and Côte, 2016), making France a European and global leader in agroecology research.

At the technical level, the agroecology plan has been built progressively along two tracks. The first was the inclusion of various support programmes for agricultural transformations that seemed compatible with the course set and with the term (MAAF, 2014b). This is the case, for example, of support for organic farming and agroforestry, or support for the reduction in the use of phytosanitary products with the 'Ecophyto' plan. New, or already in the process of being developed, elements have been added to this plan in relation to agricultural mechanisation, reducing the use of antibiotics in animal husbandry, and sustainable beekeeping. The second way, which allowed the Ministry to promote collective action, consisted in the establishment of economic and environmental interest groups (GIEE). The recognition of these groupings of farms facilitates access to French or European support schemes. 527 GIEE have been recognised since 2015, of which 492 were still active in 2019. They bring together around 8,000 farms and 9,500 farmers, or nearly 2 % of French farms.

France has bet on a "pacifying political rhetoric" (Arrignon and Bosc, 2020) aimed at embracing the widest possible range of actors. Although the concrete effects of this policy remain difficult to evaluate, or even rather inconclusive (e.g increased pesticide use despite Ecophyto's pest reduction objectives), the discursive work has borne fruit; for example, in legitimising agroecology in France and helping put it on the global agenda at FAO level (Loconto and Fouilleux, 2019). The various components of the Ministry's action have gradually been deployed to contribute to enhancing the threefold (productive, environmental and social) performance of agriculture: training (including trainers), research (and, more broadly, capitalisation of knowledge), and financial incentives (support to collective actions). However, in terms of the more radical, transformative visions of agroecology such as those from Terre et Humanism or Confédération Paysanne (Bellon and Ollivier, 2012; Calame, 2016), the policies still fall far short of what is hoped for, and represent a forced adaptation of the concept to fit existing policy programmes and priorities (Ajates Gonzalez et al., 2018). Within this national framework, situations differ among organisations. Some territories are considered as pioneer in transitions to more sustainable food systems, such as the south eastern organic 'Vallée de la Drôme-Diois' (HLPE, 2019). Some authors consider the performative indeterminacy of policy instruments as an asset for agroecological transitions (Lamine et al., 2020). These instruments enable supported farmers groups to build their own trajectory of change, which also entails difficulties in terms of implementation and evaluation.

## 2.4 Policies focusing on organic farming as an agroecological approach in Germany

In Germany, at the policy level, the focus of supporting transitions to sustainable farming and food systems is on organic farming and the term agroecology is not used in the existing strategies and schemes that promote sustainable farming. Policies in Germany indirectly support agroecological systems and promote agroecological transition (FAO, 2018). Building on the revised German Sustainability Strategy (Federal Government, 2016), a new "Organic Farming – Looking Forwards" Strategy has been developed involving the Federal States, the organic food industry and science (BMEL, 2019). The strategies aim to increase the share of federal agricultural land farmed organically towards the target of "20 % by 2030" and to facilitate the development of an appropriate policy framework and integration of a wide range of different support activities for organic farming and food.

Complementing the financial support provided to organic farming directly through the CAP's organic farming measure in the Rural Development Programmes, the Federal Scheme for Organic Farming and Other Forms of Sustainable Agriculture deals with the coordination of research on organic and other forms of sustainable farming and food production. Since its start in 2002, more than 1,100 research projects have been supported with a funding volume of some 170 million Euro. In addition, measures for knowledge transfer and advanced training programmes for value chain actors were implemented (BMEL, 2020).

Beyond the promotion of organic farming, the acknowledgement of the importance of agroecology is increasing in Germany as evidenced in discussion groups and conferences on the contributions of agroecology to sustainable farming organised by ministerial departments as well as a number of position papers published by non-governmental and civil society organisations. One prominent example is a position paper published by 59 organisations (INKOTA, 2019) calling for a transformation from industrial agriculture to agroecological farming and a commitment of the Federal Government to implement step-by-step agroecological principles in agricultural policy. In addition, a range of territorially-based initiatives support traditional and extensive farming practices and promote the implementation of agroecological practices. Examples include the Flowering Meadows scheme in Swabian Alb and the Landcare Association (Zilans et al., 2019).

In the academic discourse of the concept and importance of agroecology, recent studies (e.g. Wezel and Bellon, 2018;

Gallardo-López et al., 2018) argue that in Germany agroecology is mainly conceived as a science and largely operates within the realms of plant sciences, ecology and zoology. However, an increasing number of scientific studies and position papers highlight the need for a "greener" agricultural policy that promotes the implementation of agroecological principles and organic farming, aligned with contributions to the Sustainability Development Goals and based on smart, result-based indicators (e.g. Pe'er et al., 2020; SAB, 2019). Synergies between agroecology and organic farming need to be further utilised, converging their principles and practices to an approach that fundamentally transforms conventional agro-food systems (Migliorini and Wezel, 2017).

### 2.5 Contrasting approaches, but limited policy recognition in the United Kingdom

Agroecology in the United Kingdom has been promoted in different forms since the 1980s. From a natural science research perspective, the 'academic discipline' approach to agroecology is perhaps best represented by Rothamsted Research Institute's former Department of Agroecology[4], which was restructured in 2018 into Departments of Sustainable Agriculture and of Biointeractions and Crop Protection[5]. In 2011, Coventry University together with Garden Organic established what became the Centre for Agroecology, Water and Resilience (CAWR) in 2015[6]. Unlike Rothamsted, this academic Centre also had a high representation of social scientists, with a strong focus on the potential for the socio-economic transformation of agriculture, reflected in CAWR's 'Mainstreaming agroecology' paper (Wibbelmann et al., 2013). At the farm level, the agroecology concept is promoted most actively by the Landworkers' Alliance (LWA)[7], representing the more radical vision of international organisations such as La Via Campesina, as well as by the Oxford Real Farming Conference[8] and related initiatives.

These initiatives have developed in parallel, and sometimes in close association, with organisations for organic farming and research, like the Soil Association and the Henry Doubleday Research Association dating back to the 1940s, or the Progressive Farming Trust founded in 1980, as well as initiatives for Permaculture, Agroforestry, Conservation Agriculture (Allerton Trust) and Integrated Farming (LEAF). Reflecting this diversity of approaches, the Agricology website[9] was established in 2015, to help farmers access practical information on ecological approaches to sustainable farming, regardless of labels.

In 2014, the Land Use Policy Group of the UK nature conservation agencies commissioned a report (Lampkin et al., 2015) on the role that agroecology might play in sustainable intensification[10]. While acknowledging the social context, the report focused more on agroecosystem management concepts, consistent with the efficiency, substitution, redesign framework proposed by Hill (1985) (see also Pretty et al., 2018). In this concept, agricultural and associated environmental problems need ecological solutions, achieved by redesigning and managing agricultural ecosystems in preference to input reduction (efficiency) approaches, or replacing problem inputs with more benign alternatives (substitution). Building on this concept, the report argued that agroecology could be considered to be an inclusive framework for the range of alternative agricultural approaches that use at least some agroecological practices, though not all involve the complete rejection of agrochemicals. A subsequent report (Padel et al., 2018) looked into the process of transition at the farm level to these different agroecological alternatives. However, these reports were seen by others to be a weakening of the agroecology concept, at the expense of the social transformation agenda (Ajates Gonzalez et al., 2018).

From a policy perspective, there has been increasing discussion of agroecological perspectives as part of the debate over the UK's future agricultural and environmental policies following the 2016 referendum vote in favour of leaving the European Union. The All Party Parliamentary Group (APPG) on Agroecology has supported debates within Parliament and the LWA has produced detailed policy proposals (e.g. LWA, 2017), leading to some limited recognition in the Agriculture Bill debated in the UK Parliament in 2020[11]. However, there is some way to go in terms of institutional or financial support for farming, advice, training or research before agroecology or organic farming receive similar governmental policy recognition to that elsewhere in Europe (Lampkin and Sanders, 2021, in press).

## 3 Points of tension impacting on policy making

It is clear from the contrasting experiences even of these three case study countries with different levels of governmental support that the divergent interpretations of agroecology can impact on policy debates. Is agroecology mainly an academic discipline, an agricultural management approach or a social movement? Is it inclusive of a range of approaches advocated as options for improved agricultural sustainability, or a stand-alone alternative in an increasingly crowded space? Does it automatically exclude certain inputs, as many advocates believe, or is it flexible with respect to inputs provided that the underlying ecological principles are maintained? The issues are explored in some detail at a global level by HLPE (2019) and at a European level by Wezel and Bellon (2018). In this section we consider two of them: the social transformation agenda, and the relationship between

4 https://www.researchgate.net/institution/Rothamsted_Research/department/Department_of_Agroecology

5 https://www.rothamsted.ac.uk/science-departments

6 https://www.coventry.ac.uk/research/areas-of-research/agroecology-water-resilience

7 https://landworkersalliance.org.uk/

8 https://orfc.org.uk/about/

9 https://www.agricology.co.uk/)

10 Sustainable intensification is a term originally coined by Pretty (1997) to refer to agroecological approaches, but which subsequently acquired other meanings seen by many to be in opposition to agroecology. In part, this was due to weak conceptualisations of sustainability and concerns that intensification represented continuing with the status quo, rather than intensifying reliance on more sustainable and ecological processes.

11 https://services.parliament.uk/Bills/2019-21/agriculture/stages.html

agroecology and organic farming, which already has a well-developed policy infrastructure in a European context.

### 3.1 Agroecology and society

One way to question the policy relevance of agroecology is to ask what does it contribute, globally, to society? It is no longer just an issue of questioning the capacity of an agricultural system or practice to achieve a given set of objectives, but of understanding the wider contribution of the existence of agroecology and the debates it provokes. Agroecology, like organic farming and other related approaches, is a powerful driving force for reflection, nourished by its different facets. For agroecology, whatever its form, is a new way of "re-connecting" agriculture, science, the environment and society.

Debates about the conceptualisation and implementation of agroecology are still on-going in research institutions. The contexts of emergence and development of discourses on agroecology are manifold (Wezel et al., 2009), and a study of research institutions shows contrasting implications and internal controversies around different agroecological frameworks (Ollivier et al., 2019). At least two tensions are reflected in the framing of agroecology: firstly around the borders of science with politics, where different conceptions of scientificity are revealed; and secondly around the borders of science with the economic world, particularly when very diverse forms of agriculture coexist in one country (van Hulst et al., 2020). Previous studies on knowledge production regimes (Bonneuil and Thomas, 2009) show that research can be polarised by various players: academic ("excellence"), civic (sometimes consumerist), corporate (or professional), market and/or state actors represent different interests and priorities. Indeed, such categories can be combined. But considering agroecology as an innovative programme encourages us to explore new fields of knowledge, with transdisciplinarity integrating different forms of knowledge (Meynard, 2017) from life, earth, economic and social sciences, politics and practice.

Reality is somehow different. True transdisciplinary approaches in agroecology are scarce in European research (Fernández González et al., 2020). Scholars interact more with practitioners than with social movements, and mostly with work done outside Europe. There is also a strong disconnection and unbalanced participation between academic agroecology and agroecology as a movement (Wezel et al., 2018; Gallardo-López et al., 2018). The debates within the researchers' professional association Agroecology Europe show the difficulties of articulation between social movements and the scientific world, due to their different aims of action and temporalities. The former is focused on advocacy for the political and institutional worlds, while the latter is divided on how to articulate with the social question, which is reflected in the internal cleavage within agroecology between strong and weak visions, identified already in the 1980s (Hecht, 1987). Moreover, social sciences are often less integrated in agricultural research, with agroecology considered as a merger between agronomy and ecology, supposedly conveying a "hard" vision of agroecology (Dalgaard et al., 2003). In France, during the debate on the Law of the Future for Agriculture, Food and Forestry[12], the technicised vision conveyed by the Ministry was challenged by a new "Collective for a Peasant Agroecology"[13]. The Ministry's actions have had little impact on food sovereignty (apart from "territorial food projects") and agricultural markets, despite two attempts (inclusion of agroecology in official quality signs, and coupling of private labels with High Environmental Value certification). Arguably, the institutionalisation of agroecology in France has also impacted on the social movements by stabilising of networks.

Another drawback is the absence or weakness of frameworks that legitimise agroecological research in the formal regulations and political agendas, and of social recognition that closes the gap between research, policy and farming stakeholders acting at different scales in Europe (Wezel et al., 2018; Gallardo-López et al., 2018; Migliorini and Wezel, 2017; Monteduro et al., 2015). Forthcoming investments in both research infrastructure and science-society-policy partnerships at EU-level should contribute to bridge those gaps, reflecting increasing recognition and policy commitment.

### 3.2 Agroecology and organic farming

The development of agroecology has been strongly intertwined with that of organic farming and other alternative agricultural movements, including regenerative agriculture (itself a by-product of organic farming), agroforestry and permaculture. The organic movement has also been associated with a century long debate, also with an early focus on the soil, but to an extent with other players, with some key events where the two streams came together, for example the IFOAM Global conference in Santa Cruz in 1986. The different movements have both had a diverse mix of people (practitioners, researchers, other citizens) and issues (pollution, animal welfare, food quality, soil conservation, social justice/fairness) interacting with each other, so that there is considerable common ground between them. There is an argument that organic farming is a transitional stage en route to an agroecological future, or at least somehow less impactful and more constrained by certification and markets (Gliessman, 2015; HLPE, 2019; FAO, 2018), but this is difficult to sustain given the extensive debates in organic farming literature and research and development in several countries since the 1970s. It is also potentially counterproductive in the context of different and still conflicting definitions of agroecology and the challenges that agroecological producers have yet to resolve. FAO (2018) goes so far as to say that : "The deliberate and explicit consideration of the social and economic dimensions of food systems is one of the specific characteristics of agroecology that makes it unique compared to

[12] LOI no 2014-1170 du 13 Octobre 2014 D'avenir pour L'agriculture, L'alimentation et la Forêt (https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000029573022). Following this, agroecology is defined on the Ministry's website (but not defined in the law) as "the integrated use of nature's resources and mechanisms for the purpose of agricultural production. It combines the ecological, economic and social dimensions, and aims to make better use of the interactions between plants, animals, humans and the environment".

[13] https://www.bede-asso.org/wp-content/uploads/2014/10/Communique-agroecologie-paysanne-FR-ES-DE-EN1.pdf

organic agriculture". This ignores the substantial debates on social and economic aspects that have taken place in organic farming periodicals, conferences and standards setting forums over the last 50 years (see for example Lampkin, 1990) as well as the pioneering role of organic farmers in establishing new marketing models, including Community Supported Agriculture and other forms of shorter supply chains between producers and consumers.

One key point of difference is the development of specialist markets for organic products and the associated regulatory issues and corporate engagement. Although the biodynamic movement introduced Demeter certification much earlier, the organic market as such emerged in the 1970s, as a result of farmers needing to ensure the financial viability of their systems (in the absence at that time of any policy support). This was also a response to consumers becoming increasingly concerned about the health and environmental impacts of pesticides and other agricultural practices, with Silent Spring (Carson, 1962) representing one key turning point. However, the development of specialist markets for organic products led to the need to define standards, particularly because of the focus on defining production systems rather than the end product, in order to protect consumers and bona fide producers, and as the markets grew, states intervened with regulations to provide legal definitions. These standards and regulations focused, for understandable auditing and control reasons, more on permitted inputs and practices than on the underlying ecological principles of organic farming or the environmental and other social outcomes. While the focus on 'no chemicals' may have also reflected some consumer concerns and was simple to communicate, it has also adversely coloured the subsequent debate about the nature and role of organic farming. The growth of the market has also undoubtedly led to some commercial interests delivering the bare minimum required to meet organic standards, leading to the critique of the 'conventionalisation' and institutionalisation of organic farming (Darnhofer et al., 2010; Migliorini and Wezel, 2017). While this may be true for some organic farmers and supply chains, it ignores many others that go much further than the regulatory baseline, consistent with agroecological perspectives and the redesign principle. Arguably, the restrictions imposed by organic standards and regulations actually encourage this, as farmers need to be innovative and creative in finding ecological solutions to problems that can no longer be addressed by the use of agrochemical inputs.

In an effort to address this tension between its principles and the marketplace, the organic movement has in recent years put significant effort into refocusing on its agroecological roots, both in terms of the debate around Organic 3.0 (Arbenz et al., 2017), research agendas (Niggli, 2015) and position papers on organic farming and agroecology (IFOAM EU, 2019; INKOTA, 2019).

A challenge for agroecology more generally is exactly the same as that faced by organic farmers 50 years ago – how can the financial viability of agroecological farms be sustained, if the financial benefits of agricultural intensification are less accessible? There is already discussion around the development of markets for agroecological products, in particular in France, but this will face exactly the same dilemmas faced by the organic movement – the need for definitions communicable to consumers, the need for standards and regulations that can be audited, and the challenge of consistency with agroecological principles if premium markets are to be exploited. The same is potentially true for policy support options. Is it necessary to reinvent the wheel for agroecology? Why not recognise the commonality and work to both improve commercial organic farming using agroecological principles, and use the organic market and current policy support frameworks to support agroecological producers?

Despite the separate identities, there is a high degree of commonality between the approaches and their underlying principles (Lampkin et al., 2015; Lampkin et al., 2020). It is questionable whether they should be considered fundamentally different from each other. There is a need for bridge building between concepts, rather than creating hypothetical barriers, and it is important that future policy making takes this on board. However, while organic, regenerative, biodynamic, agroforestry and permaculture may be seen as closely aligned with agroecology, there is more of a debate about conservation agriculture, integrated pest management, climate smart, precision agriculture, circular agriculture and low input sustainable agriculture, where there is greater acceptance of agrochemical inputs. In contrast to Lampkin et al., (2015), who took a more inclusive perspective with respect to this second group, HLPE (2019) makes the distinction between agroecological and sustainable intensification approaches as separate entities. Resolving this debate, and the degree of co-option of the agroecology concept to mainstream policy and institutional perspectives, will be important for the coherence of future policy making.

The debates and tensions not only relate to farming methods, but also to issues of farm scale, corporate involvement and globalism. Many protagonists argue that small farms are in themselves more sustainable, and that agroecology can only be based on small farms, but this is not necessarily the case (Ebel, 2020). There are reasons why small farms may be less well placed to adopt agroecological approaches, not least due to limitations on specialist skills and experience and access to resources which larger farms may find easier to access. Agroecological management and system redesign approaches can also be applied on larger farms – indeed in regions where large farms are the norm, as in parts of the UK and Germany, it can be argued that an agroecological approach needs to engage with a farming structure that reflects the cultural and social characteristics and heritage of the region, rather than to attempt to re-impose a peasant farming system reflecting other human cultures. Similarly, while local, shorter food chains with direct interactions between producers and consumers may generate some benefits in terms of income retention in communities, reduction in food miles, freshness, traceability and communication, these are not necessarily guaranteed and potential impacts of climate on production methods, for example reducing the need for pesticides and energy inputs in drier or sunnier climates, might outweigh benefits from proximity.

## 4 Implications for future agroecology policies in Europe

Agroecology is currently marginal in the EU's Common Agricultural Policy (CAP) and in the policies of most Member States, including within their agri-environmental schemes. In the European context, the policy infrastructure to support organic farming, initiated in the late 1980s/early 1990s, represents the closest existing equivalent to a possible policy framework for agroecology. This includes regulations defining organic food and farming, financial support for conversion to and maintenance of organic farming, action plans to integrate supply-push (producer-focused) and demand-pull (consumer-focused) policies, and research and information programmes (Lampkin et al., 1999; Stolze and Lampkin, 2009; Meredith et al., 2018). These policies recognise and address the dual role of organic farming delivering both market opportunities meeting consumer needs and public goods for the benefit of wider society.

In order to support the more widespread adoption of agroecology to deliver environmental and social benefits as well as food and fibre, should policy makers focus on developing a completely new policy framework, in parallel to existing ones, or would it make more sense to adapt the existing policies for organic farming to encompass agroecological principles more explicitly? Critically, how important is a clear definition of agroecology to being able to implement any specific policies? The creation of an EU regulation defining organic farming (EC, 1991) was an essential pre-requisite for the inclusion of organic farming as an agri-environmental measure from 1994 (EC, 1992). Possible answers to these questions can be seen from recent European Commission policy proposals.

European-level agricultural and environmental policies are in a process of change, likely to be given new emphasis by the COVID-19 pandemic as well as the budgetary implications of Brexit. The proposals for a new CAP for the period 2021–2027 (EC, 2018), now due to be implemented in 2023, emphasised the delegation of responsibility for developing and implementing policy measures to Member States, in the context of a common framework of environmental, economic and social goals. The so-called "Green Architecture" of the new CAP comprises, in addition to the familiar Pillar 2 agri-environmental and organic farming policy support, new Pillar 1 initiatives for an enhanced baseline "conditionality" and in particular Eco-schemes that could provide a basis for supporting a range of multi-functional, agroecological system-based approaches (Lampkin et al., 2020). In a recent communication from the Commission to the European Parliament, an Agroecology Eco-scheme, including organic farming, but also more limited farming practice changes going beyond conditionality, was highlighted as one of four flagship Eco-schemes, the others being agroforestry, precision farming and carbon farming (EC, 2020c).

As part of the implementation of the European Commission's Green Deal, the Biodiversity and Farm to Fork Strategies (EC, 2020a, 2020b), are intended to be the starting point of a new debate on formulating a more sustainable and biodiversity friendly food policy, encouraging agroecology and in particular ambitious targets for the further expansion of organic farming to 25 % of EU land area by 2030. These strategies cover most of the key areas identified here and require coordination between agricultural, food, environmental and public health policies and collaboration of stakeholders across those sectors. The key challenge will be how they are realised in practice, and the extent to which member states and their regions are enabled/required to integrate them in their CAP strategic plans.

The ongoing debates over these strategies and the new CAP will offer an important opportunity for European, national and regional institutions and policy-makers to address the systemic flaws of a sectoral CAP and to align the CAP towards with the principles of sustainability, multifunctionality and public payments for public goods (Pe'er et al., 2020; ECA 2020). The potential for a sustainable agroecological transition of the whole food system will not only depend on agricultural policies, but also on other policies supporting the establishment of values-based food chains (Stevenson and Pirog, 2008), a shift in production systems supported by dietary changes (Walls et al., 2016; Poore and Nemecek, 2018) and the protection of natural resources (Wezel et al., 2016). Such a synergistic combination of action and policies to supporting agroecological transitions would address the need to reduce food loss and waste and to improve the resilience and robustness of the food system in particular by diversification (SAM, 2020) and be coherent with the ambitions of the new EU Green Deal.

In summary, a transformative policy for agroecology in Europe should:

- encompass agricultural, environmental, food and public health policy, tackling the whole of the food system in a synergistic approach;
- address technical issues, including reducing the use of problematic inputs and practices, for example by encouraging more use of legumes fixing nitrogen biologically to replace synthetic nitrogen fertiliser use, with a focus on whole farm systems, not just individual practices or commodities;
- foster diversification of production and food systems, as well as farm autonomy and adaptive capability, to improve farm resilience and capacity to absorb shocks;
- integrate biodiversity and habitat conservation within farming systems, as well as the conservation of natural resources, with a land sharing approach to agriculture and the environment (Pe'er et al., 2020; Lampkin et al., 2020; IPBES, 2018);
- tackle questions about the role of livestock in farming systems and human diets (Aubert et al., 2019), with a focus on complementarity and moderation of consumption;
- address issues of economic exploitation and power relations as well as problems of overconsumption and food waste in food chains, with implications for public health, social justice and food security;
- consider shifting the emphasis of support from land area to people employed in agriculture and related food businesses, which would make it possible to favour "job-rich"-

farms, with the capacity to implement environmental and other public good actions;
- support the process of transition, in particular recognising the different stages and the need for both learning new approaches and 'unlearning' previous convictions, requiring a fresh approach to advice, training, education and information services, for practitioners, their support agencies and more widely in society (Padel et al., 2020).

Achieving this will require broader coalitions, recognising the common ground and shared roots of agroecology, organic farming and related ideas, and building on rather than duplicating what has already been achieved. Addressing the green recovery from COVID-19 and implementing the new CAP, Green Deal and related strategies seems a good place to start.

## Acknowledgements

The input of Gerald Schwarz was funded through the European Union's Horizon 2020 research and innovation programme under grant agreement no. 773901. The input of Stéphane Bellon contributes to the project IDAE (ANR research agreement 15-CE21-0006-01).

REFERENCES

Ajates Gonzalez R, Thomas J, Chang M (2018) Translating agroecology into policy: The case of France and the United Kingdom. Sustainability 10(8):2930, doi:10.3390/su1008293

Altieri MA (ed) (1987) Agroecology: The scientific basis of alternative agriculture. Boulder, CO: Westview Press, 227 p

Arbenz M, Gould D, Stopes C (2017) ORGANIC 3.0 – the vision of the global organic movement and the need for scientific support. Org Agr 7(3):-199–207, doi:10.1007/s13165-017-0177-7

Arrignon M, Bosc C (2020) "Agroécologie" et "transition" à la française, de quoi parle-t-on? In: Bosc C, Arrignon M (eds) Les transitions agroécologiques en France. Enjeux, conditions et modalités du changement. Clermont-Ferrand: Presses Universitaires Blaise-Pascal, pp 15–36

Aubert PM, Schwoob MH, Poux X (2019) Agroecology and carbon neutrality in Europe by 2050: what are the issues?: Findings from the ten years for Agroecology (TYFA) modelling exercise. Study No 02/19. Paris: Institut du développement durable et des relations internationales (IDDRI)

Azzi G (1928) Agricultural Ecology (in Italian). Turin: Edition Tipografia Editrice Torinese, 237 p

Bellon S, Ollivier G (2012) L'agroécologie en France : l'institutionnalisation d'utopies. In: Goulet F, et al (eds) L'agroécologie en Argentine et en France. Regards croisés. Paris: L'Harmattan, pp 55–90

Bellon S, Ollivier G (2018) Institutionalizing agroecology in France: Social circulation changes the meaning of an idea. Sustainability 10(5):1380, doi:10.3390/su10051380

Bensin BM (1940) Agroecology as a basic science of agriculture. Bulletin of the Ecological Society of America(21):2–13

BMEL (2019) Zukunftsstrategie ökologischer Landbau: Impulse für mehr Nachhaltigkeit in Deutschland. 2. Auflage. Berlin: Bundesministerium für Ernährung und Landwirtschaft

BMEL (2020) Organic Farming in Germany. Berlin: Federal Ministry of Food and Agriculture (BMEL)

Bonneuil C, Thomas F (2009) Gènes pouvoirs et profits. Recherche publique et régimes de production des savoirs de Mendel aux OGM. Paris: Quae, FPH, IRD

Calame M (2016) Comprendre l'agroécologie. Origines, principes et politiques. Paris: Éditions Charles Léopold Meyer

Caquet T, Gascuel C, Tixier-Boichard M (eds) (2020) Agroécologie des recherches pour la transition des filères et des territoires. Paris: Quae Ed

Carson R (1962) Silent Spring. Boston: Houghton Mifflin

Dalgaard T, Hutchings NJ, Porter JR (2003) Agroecology, scaling and interdisciplinarity. Agric Ecosyst Environ 100(1):39–51, doi:10.1016/S0167-8809(03)00152-X

Darnhofer I, Lindenthal T, Bartel-Kratochvil R, Zollitsch W (2010) Conventionalisation of organic farming practices: from structural criteria towards an assessment based on organic principles. A review. Agron Sustain Dev 30(1):67–81, doi:10.1051/agro/2009011

Doré T, Bellon S (2019) Les mondes de l'agroécologie. Paris: Quae Ed

Ebel R (2020) Are small farms sustainable by nature? Review of an ongoing misunderstanding in agroecology. Challenges in Sustainability 8(1), doi:10.12924/cis2020.08010017

EC (1991) Council Regulation (EEC) No 2092/91 of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs. Official Journal of the European Communities L198(22.7.91):1–15

EC (1992) Council Regulation (EEC) No 2078/92 of the 30 June 1992 on agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside. Official Journal of the European Communities L215(30.7.92):85–90

EC (2018) Proposal for a regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common Agricultural Policy (CAP Strategic Plans). COM(2018) 392 final. Brussels: European Commission

EC (2020a) A 'Farm to Fork' strategy: for a fair, healthy and environmentally-friendly food system. Communication from the Commission the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2020) 381 final. Brussels: European Commission

EC (2020b) EU Biodiversity Strategy for 2030: Bringing nature back into our lives. Communication from the Commission the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2020) 380 final. Brussels: European Commission

EC (2020c) Four flagship Eco-schemes as announced in the Farm to Fork Strategy [online]. Unpublished communication to the European Parliament, 09.10.20. Brussels: European Commission, retrieved from <https://www.arc2020.eu/commission-proposes-four-flag-ship-eco-schemes-arc2020-analysis/> [at 29 Dec 2020]

ECA (2020) Biodiversity on farmland: CAP contribution has not halted the decline. Special Report 2020/13. Luxembourg: European Court of Auditors

FAO (2018) Agroecology in Europe and Central Asia: an overview. Budapest: Food and Agriculture Organization of the United Nations

Federal Government (2016) Germany's National Sustainability Strategy. Berlin: Federal Government of Germany

Fernández González C, Ollivier G, Bellon S (2020) Transdisciplinarity in Agroecology: practices and perspectives in Europe. Agroecol Sust Food, doi: 10.1080/21683565.2020.1842285

Francis C, Lieblein G, Gliessman S, Breland TA, Creamer N, Harwood R, Salomonsson L, Helenius J, Rickerl D, Salvador R, et al. (2003) Agroecology: The ecology of food systems. J Sustain Agr 22(3):99–118, doi:10.1300/J064v22n03_10

Gallardo-López F, Hernández-Chontal M, Cisneros-Saguilán P, Linares-Gabriel A (2018) Development of the concept of agroecology in Europe: A review. Sustainability 10(4):1210, doi:10.3390/su10041210

Gliessman SR (2015) Agroecology: Theecology of sustainable food systems, 3rd ed. Hoboken: CRC Press, 386 p

Griffon M (2014) Agroécologie et agriculture écologiquement intensive: principes et perspectives scientifiques. Paris: Association Française des Biotechnologies Végétales, AEI

Hecht S (1987) The evolution of agroecological thought. In: Altieri MA (ed) Agroecology: The scientific basis of alternative agriculture. Boulder, CO: Westview Press

Hill SB (1985) Redesigning the food system for sustainability. Alternatives 12:32–36

HLPE (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome

IFOAM EU (2019) Organic and agroecology: working to transform our food system. Position paper on agroecology. Brussels: IFOAM EU Group

INKOTA (2019) Positionspapier Agrarökologie stärken: Für eine grundlegende Transformation der Agrar- und Ernährungssysteme. INKOTA Netzwerk

IPBES (2018) Regional assessment report on biodiversity and ecosystem services for Europe and Central Asia | IPBES: Summary for Policymakers. Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

Lamine C, Derbez F, Barbier M (2020) L'indétermination performative d'instruments d'action publique pour la transition agroécologique. In: Bosc C, Arrignon M. (eds) Les transitions agroécologiques en France. Enjeux, conditions et modalités du changement. Clermont-Ferrand: Presses Universitaires Blaise-Pascal, pp 37–51

Lampkin N (1990) Organic farming, 1st edn. Ipswich: Farming Press, 700 p

Lampkin N, Foster C, Padel S, Midmore P (1999) The policy and regulatory environment for organic farming in Europe. Hohenheim: University of Hohenheim, Organic farming in Europe: economics and policy 1

Lampkin N, Sanders J (2021 in press) Policy support for organic farming in the European Union: 2011, 2015 and 2019. Braunschweig: Thünen Institute of Farm Economics

Lampkin N, Stolze M, Meredith S, Porras M de, Haller L, Mészáros D (2020) Using Eco-schemes in the new CAP: a guide for managing authorities. Brussels: IFOAM EU Group

Lampkin NH, Pearce BD, Leake AR, Creissen H, Gerrard CL, Girling R, Lloyd S, Padel S, Smith J, Smith LG, et al. (2015) The role of agroecology in sustainable intensification: A report for the Land Use Policy Group. Newbury and Fordingbridge: Organic Research Centre, Elm Farm and Game & Wildlife Conservation Trust

Loconto A, Fouilleux E (2019) Defining agroecology: Exploring the circulation of knowledge in FAO's Global Dialogue. International Journal of Sociology of Agriculture and Food 25(2):116–137, doi:10.48416/ijsaf.v25i2.27

López-i-Gelats F, Di Masso M, Binimelis R, Rivera-Ferre MG (2016) Agroecology. In: Thompson PB, Kaplan DM (eds) Encyclopedia of food and agricultural ethics. Dordrecht: Springer Netherlands, pp 1–5

LWA (2017) A People's Food Policy. Landworkers Alliance

MAAF (2014a) Le plan d'action global pour l'agro-écologie. Paris: Ministere de l'Agriculture de l'Agroalimentaire et de la Foret

MAAF (2014b) Les 10 clés de l'agro-écologie. Paris: Ministere de l'Agriculture de l'Agroalimentaire et de la Foret

Meredith S, Lampkin N, Schmid O (2018) Organic Action Plans: Development, implementation and evaluation, 2nd Edition. Brussels: IFOAM EU Group

Meynard J-M (2017) L'agroécologie, un nouveau rapport aux savoirs et à l'innovation. OCL 24(3):D303, doi:10.1051/ocl/2017021

Migliorini P, Wezel A (2017) Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review. Agron. Sustain. Dev. 37(6):63, doi:10.1007/s13593-017-0472-4

Monteduro M, Buongiorno P, Di Benedetto S, Isoni A (eds) (2015) Law and agroecology: A transdisciplinary dialogue. Berlin: Springer, 494 p

Nicot R, Bellon S, Loconto A, Ollivier G (2018) The European networks of research, education and training stakeholders in agroecology. Open Agriculture 3(1):537–552, doi:10.1515/opag-2018-0058

Niggli U (2015) Incorporating agroecology into organic research: an ongoing challenge. Sustainable Agriculture Research 4(3):149, doi:10.5539/sar.v4n3p149

Ollivier G, Bellon S (2021) Pour une histoire de l'agroécologie en Europe. In: Hubert B, Couvet D (eds) La transition agroécologique. Quelles perspectives en France? Acad Agric de France. Paris: Presses des Mines

Ollivier G, Bellon S, Abreu Sá Td, Magda D (2019) Aux frontières de l'agroécologie. Les politiques de recherche de deux instituts agronomiques publics français et brésilien. Natures Sciences Societes 27(1):20–38, doi:10.1051/nss/2019017

Padel S, Levidow L, Pearce B (2020) UK farmers' transition pathways towards agroecological farm redesign: evaluating explanatory models. Agroecol Sust Food 44(2):139–163, doi:10.1080/21683565.2019.1631936

Padel S, Rubinstein O, Woolford A, Egan J, Leake A, Levidow L, Pearce B, Lampkin N (2018) Transitions to Agroecological Systems: Farmers' Viewpoints. A Report for the Landuse Policy Group. Newbury and Fordingbridge: Organic Research Centre and Game and Wildlife Conservation Trust

Pe'er G, Bonn A, Bruelheide H, Dieker P, Eisenhauer N, Feindt PH, Hagedorn G, Hansjürgens B, Herzon I, et al. (2020) Action needed for the EU Common Agricultural Policy to address sustainability challenges. People and Nature 2(2):305-316, doi:10.1002/pan3.10080

Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360(6392):987–992, doi:10.1126/science.aaq0216

Pretty J, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HCJ, Goulson D, Hartley S, Lampkin N, Morris C, et al. (2018) Global assessment of agricultural system redesign for sustainable intensification. Nature Sustainability 1(8):441–446, doi:10.1038/s41893-018-0114-0

Pretty JN (1997) The sustainable intensification of agriculture. Natl Resour Forum 21(4):247–256, doi:10.1111/j.1477-8947.1997.tb00699.x

Rivera-Ferre MG (2018) The resignification process of Agroecology: Competing narratives from governments, civil society and intergovernmental organizations. Agroecol Sust Food 42(6):666–685, doi:10.1080/21683565.2018.1437498

SAB (2019) Designing an effective agri-environment-climate policy as part of the post-2020 EU Common Agricultural Policy: Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection. Berlin: Bundesministerium für Ernährung und Landwirtschaft

SAM (2020) Towards a Sustainable Food System: Moving from food as a commodity to food as more of a common good : independent expert report. Scientific Opinion 8. Luxembourg: Publications Office of the European Union

Sevilla Guzman E, Woodgate G (1997) Sustainable rural development: from industrial agriculture to agroecology. In: Redclift M, Woodgate G (eds) The international handbook of environmental sociology. Cheltenham: Edward Elgar

Soussana J-F, Côte F (2016) Agro-écologie: le positionnement des recherches de l'Inra et du Cirad. Paris: INRA, CIRAD

Stevenson GW, Pirog R (2008) Values-based supply chains: Strategies for agrifood enterprises of the middle. In: Lyson TA, Stevenson GW, Welsh R (eds) Food and the mid-level farm. The MIT Press, pp 119–144

Stolze M, Lampkin N (2009) Policy for organic farming: Rationale and concepts. Food policy 34(3):237–244; doi:10.1016/j.foodpol.2009.03.005

Tischler W (1965) Agrarökologie. Jena: VEB G Fischer

van Hulst F, Ellis R, Prager K, Msika J (2020) Using co-constructed mental models to understand stakeholder perspectives on agro-ecology. Int Journ Agric Sustain 18(2):172–195, doi:10.1016/j.foodpol.2009.03.005

Walls HL, Cornelsen L, Lock K, Smith RD (2016) How much priority is given to nutrition and health in the EU Common Agricultural Policy? Food policy 59:12–23, doi:10.1016/j.foodpol.2015.12.008

Wezel A, Bellon S (2018) Mapping Agroecology in Europe. New Developments and Applications. Sustainability 10(8):2751, doi:10.3390/su10082751

Wezel A, Bellon S, Dore T, Francis C, Vallod D, David C (2009) Agroecology as a science, a movement and a practice: A review. Agron Sustain Dev 29(4):503–515, doi:10.1051/agro/2009004

Wezel A, Brives H, Casagrande M, Clement C, Dufour A, Vandenbroucke P (2016) Agroecology territories: places for sustainable agricultural and food systems and biodiversity conservation. Agroecol Sust Food 40(2):-132–144, doi:10.1080/21683565.2015.1115799

Wezel A, David C (2020) Policies for agroecology in France: implementation and impact in practice, research and education. Landbauforsch J Sustainable Organic Agric Syst 70(2):66–76, doi:10.3220/LBF1608660604000

Wezel A, Goris M, Bruil J, Félix G, Peeters A, Bàrberi P, Bellon S, Migliorini P (2018) Challenges and action points to amplify agroecology in Europe. Sustainability 10(5):1598, doi:10.3390/su10051598
Wezel A, Herren BG, Bezner Kerr R, Barrios E, Rodrigues Gonçalves AL, Sinclair F (2020) Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. Agron Sustain Dev 40, doi:10.1007/s13593-020-00646-z
Wibbelmann M, Schmutz U, Wright J, Udall D, Rayns F, Kneafsey M, Trenchard L, Bennett J, Lennartsson-Turner M (2013) Mainstreaming agroecology: Implications for global food and farming systems. Centre for Agroecology and Food Security, Coventry University
Zilans A, Vanni F, Povellato A (2019) Inventory of mmarket and policy Incentives supporting AEFS. Understanding and improving the sustainability of agro-ecological farming systems in the EU: UNISECO Project Report, doi:10.5281/zenodo.4453259

RESEARCH ARTICLE

# Minor changes in collembolan communities under different organic crop rotations and tillage regimes

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Received: March 27, 2020
Revised: June 17, 2020
Revised: August 24, 2020
Accepted: September 10, 2020

HIGHLIGHTS

- **Species richness and abundance of collembolans are not affected by tillage and crop rotations in organic farming systems.**
- **There is some evidence that the relative share of euedaphic collembolans is an indicator of management impacts.**
- **Collembolan communities are more influenced by crop type and crop cover than by specific crop rotations or differences in tillage regime.**

KEYWORDS **soil biodiversity, eco-morphological index (EMI), soil tillage, organic matter**

## Abstract

An aim of organic farming is to reduce negative impacts of agricultural management practices on physical, chemical, and biological soil properties. A growing number of organic farmers is trying out methods of reduced tillage to save costs, protect humus and to foster natural processes in the soil. Furthermore, techniques like increasing crop rotation diversity and reduced tillage are discussed under the topics of agroecology or ecological intensification also for implementation in non-organic farming systems.

The question arises as to whether these practices are positively impacting on soil ecosystems and which indicators can be used to describe these impacts. Collembolans are a widely distributed group of the soil mesofauna. They are mainly characterised as secondary decomposers feeding on fungi and other microorganisms. We investigated the influence of different long-term organic crop rotations (mixed farming with animal husbandry versus stockless arable) and the short term effects of two years of different tillage systems (conventional tillage versus reduced tillage) on the abundance, species richness, species composition, and selected species traits (life forms) of collembolan communities.

Although not significant, some trends are evident. Species composition of collembolan communities responded to expected alterations in soil moisture mediated by different crop sequences and inter-annual effects rather than to different management practices. The proportion of euedaphic collembolan individuals tended to increase in soil environments that offered more stable habitat conditions from increased availability of organic matter.

## 1 Introduction

Agriculture impacts directly and severely on soil biodiversity (Orgiazzi et al., 2016). Negative effects are especially expected in intensively managed systems with simple cropping sequences (e.g. Eisenhauer, 2016). To foster sustainability, soil fertility, biodiversity and nutrient supply from the soil, organic farming uses diverse crop rotations, which include different leguminous crops, and rely on organic fertilisation. In organic mixed farming systems, crop nutrition relies on the application of livestock manure and the inclusion of forage and grain legumes. Besides mixed farming systems including animal husbandry, stockless arable cropping systems without manure input are used in organic farming. Their fertilisation is based on N-fixation by legumes and input of crop residues and green manure. In summary, that the main differences between crop rotations of organic farming systems with and without livestock keeping are the form of organic fertiliser used and the proportion of legumes.

Regardless of the fertilisation regime, a common feature of most organic crop rotations is the use of a mouldboard plough, mainly for weed management. As the negative impacts of regular ploughing for different soil functions are well known (Peigné et al., 2007), in recent years different approaches have

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been presented to integrate reduced tillage practices into crop rotations in organic farming systems to enhance system sustainability (e.g. Mäder and Berner, 2012; Moos et al., 2016). In general, reducing tillage intensity has positive effects such as reducing the risk of soil erosion or increased macroporosity. Nevertheless, in organic farming, reducing the intensity of soil tillage is hindered by specific challenges such as increasing weed pressure, restricted N-availability, or restrictions in crop choice (Peigné et al,. 2007).

The aim of our project was to investigate the influence of different management practices in organic cropping systems on the soil macro- and mesofauna. Complementing a report about effects on earthworms (Moos et al., 2016), this paper considers the influence of crops, crop rotations and tillage regimes on collembolans.

The investigation of widely distributed soil fauna groups such as earthworms and microarthropods, which hold key positions within soil food webs, can shed light on the impact of management practices on soil ecosystems. Collembolans are likely to be good indicators for soil conditions because they are widely distributed (Hopkin, 1997). Due to short life cycles of the species, composition and abundance of collembolan communities are expected to rapidly adapt to and reflect environmental changes. This response might be further enhanced through their function as secondary decomposers, feeding on fungi and microorganisms, which links them closer to the environment than predatory or herbivorous animals (Greenslade, 2007).

The influence of organic fertilisers on collembolan communities is still under debate. Platen and Glemnitz (2016) found a positive effect applying digestate from biogas production on collembolan abundance in a two-year field experiment. Kautz et al. (2006) showed a positive effect of annual applications of straw and green manure. Kanal (2004) also found a positive fertilisation effect when applying cattle manure but highlighted additional seasonal variations in abundance. In contrast, Pommeresche et al. (2017) described negative short-term effects of slurry application on collembolan abundance, with more negative effects for epigeic than endogeic species. None of the studies found any consistent effect on collembolan community composition. Therefore, the influence of organic fertilisation on characteristics of collembolan communities is at least mediated by the type of organic matter and the timing of application.

As for organic fertilisation, there are different results from examinations of the effects of tillage intensity on collembolan communities. Brennan et al. (2006) found that reduced tillage increases collembolan abundance, and Miyazawa et al. (2002) ascribed the related negative effect of conventional tillage on collembolan abundance to modified soil temperature, humidity and pore size distribution. In contrast, van Capelle et al. (2012) found a significant overall reduction in abundance and species diversity with decreasing tillage intensity. This result was however affected by interacting effects of soil texture and collembolan life-form. Negative effects of reduced tillage were shown for atmobiont and euedaphic species in loamy soils (van Capelle et al., 2012). Although euedaphic species are well adapted to live within the soil, they rely on the maintenance of stable habitat conditions (Jeffery et al., 2010), especially on permanent pore space as they are not burrowing. On clay soils, reduced tillage can lead to a decrease in pore volume, which is likely to have a negative effect on euedaphic collembolans (e.g. Dittmer and Schrader, 2000).

Compared to euedaphic collembolans, hemiedaphic and atmobiont species are less dependent on the soil structure, as they inhabit the upper soil layer, the litter layer, or the soil surface. Other factors such as humidity near the soil surface and shading influence these life-forms (see above, c.f. Pommeresche et al., 2017). Thus, relative proportions of euedaphic, hemiedaphic and atmobiont species should indicate an impact of soil tillage intensity.

Besides fertilisation and tillage regimes, the characteristics of the cultivated crops influence soil conditions and thereby organisms inhabiting the soil. Different crop classes (e.g. cereals versus root crops) can influence evapotranspiration differently and thereby soil moisture and humidity on the soil surface. Legumes influence the soil specifically through their symbiosis with nitrogen fixing bacteria in root nodules. Some studies indicate positive effects of the presence of legumes on collembolan abundance and diversity in grassland due to increased microbial biomass, and higher litter quality (e.g. Sabais et al., 2011). For arable land, some studies have been conducted comparing the influence of simple crop rotations (without legumes) and more complex crop rotations (with legumes) on collembolan communities (Andrén and Lagerlöf, 1983; Jagers Op Akkerhuis et al., 1988). However, these studies did not give consistent results, with complex crop rotations having both positive and no effect on collembolan abundance.

In the study reported here, we examined how collembolan communities respond to different management practices in two organic arable crop rotations on the same experimental station, i.e. under comparable soil-climate and agro-technical conditions. Effects of tillage and crop rotation, as well as effects of crop classes and annual fluctuations (e.g. precipitation), on species richness, abundance, and life-form and species composition of collembolan communities were analysed. We focussed on the question which characteristics of collembolan communities are indicative of the effects of different crop rotations or tillage regimes in organic farming.

## 2 Material and methods

### 2.1 Study site

The study was conducted at the experimental station of the Thünen Institute of Organic Farming in Trenthorst/Wulmenau, Schleswig Holstein, northern Germany (53°46'N, 10°31'E). The site has been managed according to the EU Organic Standards 2092/91 and 834/2007 since conversion from conventional farming in 2001. The farming area is nearly flat and the soil conditions are homogeneous. The soils on the site are Stagnic Luvisols derived from boulder clay with silty-loamy texture and bulk densities of the topsoil between 1.3 to 1.5 Mg m$^{-3}$. The Atlantic climate, with a mean annual precipitation of 700 mm, relatively well-distributed throughout the year and a mean annual temperature of 8.8 °C, generally offers favourable cropping conditions. Dry periods and low temperatures can limit N-mineralisation in the heavy soils in early spring. The C:N-ratio of about 10 lies in a range which is typical for high yielding agricultural land (Blume et al., 2010). According to German fertilisation recommendations, soils are sufficiently supplied with P, K, and Mg. The apparent soil pH of 6.3 to 6.5 is typical for arable land in temperate regions.

Within the experimental station, four crop rotations were established: livestock I (L I), livestock II (L II), livestock III (L III) and stockless (SL) (*Figure 1*). The crop rotations L I to L III are part of mixed farming systems and have been designed to serve the needs of different livestock. Livestock manure (slurry and solid manure) from one central stock was applied to all fields of these three crop rotations. Furthermore, the crop rotations comprised similar elements (*Table 1*). Therefore, fields from the three rotations of the 'mixed' systems (L I, L II, L III) can be seen as replicates when cultivated with identical crops. The stockless rotation (SL) differs from the livestock-based rotations (L I to L III) in organic fertilisation and organic matter backflow through crop residues (c.f. 2.2).

Each field on the experimental station is identified by a unique field-code and includes one or two long-term monitoring plots (LTM-plot) of one hectare each (*Figure 1*). Generally, within each LTM-plot, four geo-referenced long-term sampling points (LTM-point) are located in a square at a distance of 60 m. Monitoring plots are stretched to cover one hectare in narrow fields and the LTM-points are then located in a zigzag with distances of 30 m (*Figure 1*). Soil sampling distances larger than 20 to 50 m assure the inclusion of spatial variability of chemical and physical soil parameters in this landscape (Haneklaus et al., 1998).

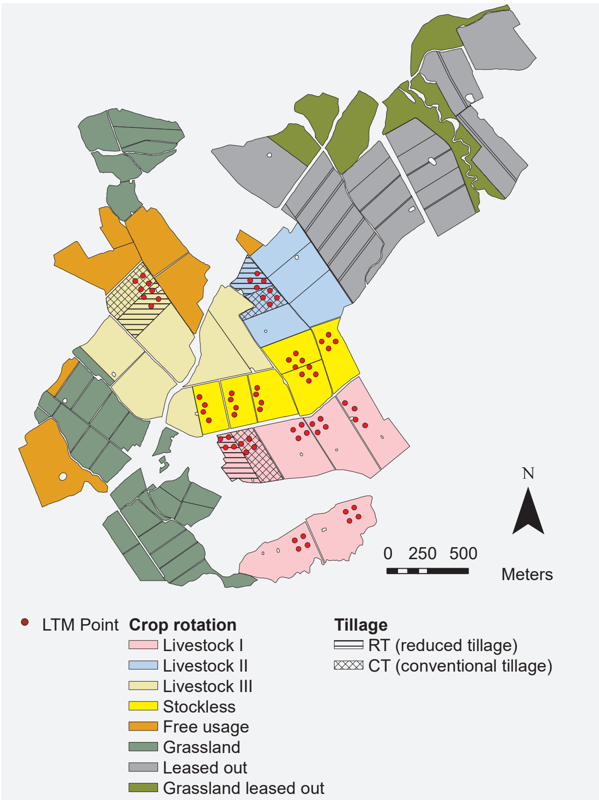


FIGURE 1
Map showing the experimental farm in Trenthorst/Wulmenau, Germany and the different farming systems realised within the farm. Red circles indicate the location of long-term monitoring (LTM) points used for this study.

TABLE 1
Crop rotations (livestock I, livestock II, livestock III, stockless) and average soil conditions within the upper 30 cm of soils in 2012 on the fields of the experimental farm in Trenthorst/Wulmenau. The crop rotations comprise five (livestock II), six (livestock I, stockless) or seven (livestock III) fields.

| Crop rotation | Livestock I | Livestock II | Livestock III | Stockless |
|---|---|---|---|---|
| Crops | clover-grass | clover-grass | clover-grass | red clover |
| | clover-grass | maize | clover-grass | winter wheat |
| | maize | winter wheat | spring barley | spring barley |
| | winter wheat | field pea/spring barley | field pea/false flax | field pea |
| | field bean/oat | triticale | winter barley | winter rape |
| | triticale | | field bean | triticale |
| | | | triticale | |
| pH | 6.4 ± 0.1 | 6.4 ± 0.0 | 6.3 ± 0.1 | 6.5 ± 0.1 |
| Nutrient content (mg 100g$^{-1}$) | | | | |
| P | 7.0 ± 0.3 | 8.6 ± 0.4 | 6.1 ± 0.4 | 7.7 ± 0.3 |
| K | 11.9 ± 0.5 | 16.1 ± 0.8 | 13.0 ± 1.2 | 11.0 ± 0.4 |
| Mg | 10.3 ± 0.3 | 11.6 ± 0.2 | 11.8 ± 0.3 | 11.3 ± 0.3 |
| Texture (g kg$^{-1}$) | | | | |
| Clay (< 2 µm) | 23 ± 1 | 18 ± 2 | 24 ± 3 | 23 ± 1 |
| Silt (2–50 µm) | 35 ± 1 | 33 ± 3 | 40 ± 3 | 37 ± 0 |
| Sand (50–2000 µm) | 42 ± 2 | 48 ± 4 | 35 ± 2 | 39 ± 1 |

P and K: CAL extract (Schüller, 1969), Mg: $CaCl_2$ extract (Schachtschabel, 1954), Mean ± standard deviation.

The German Weather Service (DWD, Deutscher Wetterdienst) provided information about soil moisture for the years 2012 and 2014 (*Figure 2*). Water availability under winter wheat in the top 30 cm was calculated for soil and weather conditions at the experimental station using the AMBAV model (Löpmeier, 1994).

## 2.2 Study design

To evaluate the influence of different management practices on collembolan communities in organic farming we compared (i) two crop rotations (livestock I *versus* stockless) and (ii) conventional tillage with mouldboard ploughing *versus* reduced tillage without mouldboard ploughing (*Figure 1*).

In (i) we evaluated the influence of one decade of different organic crop rotations on collembolan communities. The management of the crop rotations mainly differed in the share of forage legumes (*Table 1*), in the amount of plant material remaining on the fields (green mulch and straw) and in farmyard manure application (*Table 2*). We sampled all six fields of the livestock I (L I) and all six fields of the stockless (SL) rotation on 29 May 2012.

Since a crop rotation-independent influence of different crop classes (grains, legumes, forage crops) could not be excluded, this was also examined.

In (ii) we studied the effect of soil tillage on collembolan communities within a short-term experiment. Therefore, in summer 2012 we split one field from each of the L I, L II and L III rotations (*Figure 1*). Afterwards in each of the three rotations, one field-half was managed with ploughing (CT: conventional tillage) and the other field-half without ploughing (RT: reduced tillage). Within our study, conventional and reduced tillage were defined according to ASAE (2005). Conventional tillage included the use of a two-sided mouldboard plough, with a working depth of 25 to 30 cm, whereas no mouldboard plough was used in the field-halves managed with reduced tillage. In RT, tillage depth was a maximum of 15 cm without soil inversion. In RT, a chisel plough and a rotary harrow were used. Therefore, the reduced tillage regime in our study is rather intensive compared to much less intensive approaches like no-till. The two different tillage regimes were applied in two successive years. In 2012 before growing triticale and in 2013 before growing clover-grass. The soil management practices carried out are summarised in *Table 3*. We sampled the field-halves on 29 May 2012

TABLE 2

Characteristics of fertilisation and crop residue management on the fields of the livestock I and stockless rotation in the harvest years 2002 to 2012. For management measures the absolute number of events within 10 years is given.

| | Livestock I | Stockless |
|---|---|---|
| N from organic fertilisers (kg ha$^{-1}$ a$^{-1}$) | 39–62 | – |
| Organic matter from organic fertilisers (kg ha$^{-1}$ a$^{-1}$) | 954–1318 | – |
| Liming (kg ha$^{-1}$ a$^{-1}$) | 0–300 | – |
| Plant residues remaining on the field (not clover-grass) | 2–3 | 7–8 |
| Years with clover-grass | 2–4 | 1–2 |
| Mulching of clover grass | 0–3 | 1–4 |
| Ploughing of clover-grass | 1–2 | 1–2 |

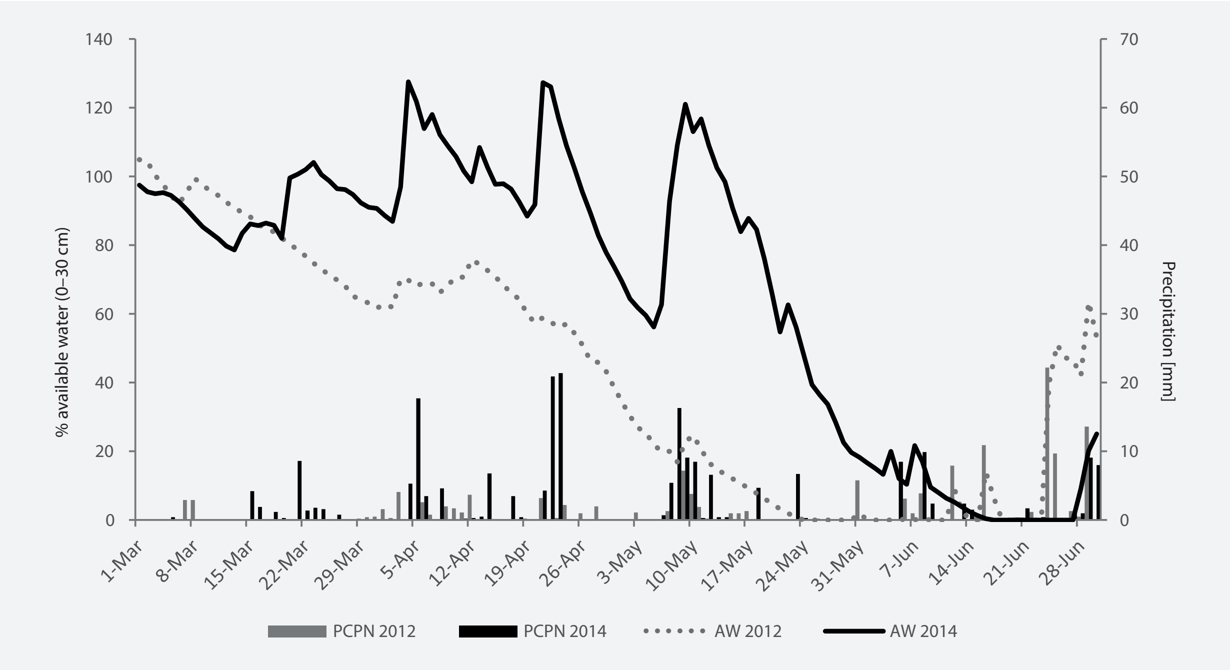


FIGURE 2

Precipitation (PCPN) and available water (AW) under winter wheat in Trenthorst/Wulmenau, Germany in 2012 and 2014 according to AMBAV model.

TABLE 3

Agricultural measures applied for soil management on the three experimental fields, each belonging to one out of three livestock-based farming systems (livestock I–III), in 2011, 2012, and 2013. CT: conventional tillage; RT: reduced tillage

| | | 2011/2012[a] | | | 2012 | | | | | | 2013 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Livestock I | | Livestock II | | Livestock III | | Livestock I | | Livestock II | | Livestock III | |
| Agricultural machinery used (ASABE, 2009) | Working depth (cm) | Livestock I | Livestock II | Livestock III | CT | RT | CT | RT | CT | RT | CT | RT | CT | RT | CT | RT |
| Chisel plough for stubble cultivation | 10–15 | 04 Oct | 23 Sep | 03 Oct | 19 Sep | 19 Sep | 09 Sep | 09 Sep | 05 Sep | 05 Sep | 12 Aug | 12 Aug | (2x) 08 Aug | (2x) 08 Aug | 11 Aug | 11 Aug |
| Two-way mouldboard plough (5-furrow) | 25–30 | 19 Oct | 20 Oct | 20 Oct | | | | | | | | | | | | |
| Two-way mouldboard plough (5-furrow) with packer | 25–30 | | | | 20 Sep | | 10 Sep | | 08 Sep | | | | 13 Aug | | 14 Aug | |
| Two-way mouldboard plough (4-furrow) | 25–30 | | | | | | | | | | 18 Aug | | | | | |
| Chisel plough | 10–15 | | | | | | | (2x) 17 Sep | | (2x) 17 Sep | 15 Aug | 15 Aug | 14 Aug | 14 Aug | 15 Aug | 15 Aug |
| Spring teeth harrow | 10–15 | 25 Mar | 22 Mar | | | | 18 Sep | | (2x) 18 Sep | | | | | | | |
| Rotary harrow | 10 | | | | | 20 Oct | (2x) 19 Sep | | 18 Sep | | | | | | 16 Aug | 16 Aug |
| Seed drill + front-mounted disc harrow | 5–10 | 26 Mar | 24 Mar | 25 Mar | 21 Oct | 21 Oct | 19. Sep | 19 Sep | 19 Sep | 19 Sep | 29 Aug | 29 Aug | 21 Aug | 21 Aug | 18 Aug | 18 Aug |
| Land roller | | 25 Mar | 22 Mar | | | | | | | | | | | | | |

a) Cultivation of the spring-grown crops field bean/oat, field pea/spring barley, and field bean, respectively.

(before introducing the different tillage systems) and again after two years on 19 May 2014 to assess the influence of tillage on collembolan communities. In 2012, the fields were planted with spring grown grain-legume cereal mixtures or pure grain-legumes (L I: field bean/oat; L II: field pea/spring barley; L III: field bean). In 2014, all fields were planted with winter grown clover-grass.

Samples taken in 2012 from the half-field subsequently managed with CT on the field of the L I rotation have also been part of the dataset when comparing the crop rotations L I and SL. Since annual effects could not be excluded, these were also examined.

## 2.3 Sampling and identification of collembolans

According to our study design, at each LTM-point two soil samples (subsamples) were collected with an auger (effective diameter 4 cm, depth 10 cm) resulting in eight samples per field half/field (*Figure 1*). This soil sampling resulted in 96 samples for the comparison of crop rotations (L I *versus* SL) in 2012. It resulted in 48 samples in both 2012 and 2014 for the comparison of tillage regimes (CT *versus* RT). The soil mesofauna was extracted from the whole samples using a MacFadyen high-gradient extractor (MacFadyen, 1961). After collection in monoethylenglycol, the extract was transferred to 96 % ethanol for storage. Since a first inspection of the samples from May 2012 showed that many collembolan individuals could be extracted from the individual samples, two out of eight samples per field-half/field were randomly selected to reduce the amount of work to a manageable level. Attention was paid to always select samples from two different LTM-points. From these two samples collembolan individuals were sorted out from the extract, counted and stored separately in ethanol. The individuals were than mounted on glass microscope slides and identified at the species level (max. magnification 400x) according to Hopkin (2007). If necessary, additionally identification keys by Gisin (1960), Bretfeld (1999), Potapov (2001), Thibaud et al. (2004), Dunger and Schlitt (2011), or Jordana (2012) were used. The nomenclature used followed the system proposed by Hopkin (2007).

*Heterosminthurus bilineatus* Group, *Protaphorura armata* Group, *Sminthurinus aureus* Group, and *Sminthurus viridis* Group were identified according to Hopkin (2007) as complexes of species. Furthermore, when discussing the genera *Desoria* and *Isotomurus*, Hopkin (2007) mentions difficulties in separating some species in these genera. Therefore, he summarises them into species groups *Desoria tigrina* Group and *Isotomurus palustris* Group, which we adopted in the identification process.

## 2.4 Life-form traits of collembolans

We used the method proposed by Martins da Silva et al. (2016) to classify collembolan species according to their adaptation to living within the soil by calculating an eco-morphological index (EMI). This enabled us to calculate a weighted mean EMI value for each collembolan sample. This is a so-called mean trait value (mT) (Vandewalle et al., 2010).

In addition to using the EMI mT-values for describing collembolan communities, we aimed to visually compare the composition of life-forms from different collembolan communities using ternary diagrams (c.f. 2.5.3). Thus, we used publications by Stierhof (2003), Chauvat et al. (2007), Sticht et al. (2008), and Salamon et al. (2011) to assign the calculated EMI values to one of the three life-forms atmobiont, hemiedaphic, or euedaphic (*Table 4*). We assume that species with the same EMI score belong to the same life-form

**TABLE 4 (PART 1)**

Life-forms (LF) of collembolan species as derived from eco-morphological index (EMI) and publications of Stierhof (2003), Chauvat et al. (2007), Sticht et al. (2008), and Salamon et al. (2011). EMI (eco-morphological index) scores according to Martins da Silva et al. (2016). at: atmobiont; ep: epedaphic; he: hemiedaphic; eu: euedaphic. NA: No data available.

| | Abbreviation | Frequency (%)[a] | Ocelli | Antenna | Furca | Scales/hairs | Pigmentation | **EMI according to Martins da Silva et al. (2016)** | Life-form according to Chauvat et al. (2007) | Life-form according to Sticht et al. (2008) | Life-form according to Stierhof (2003) | Life-form according to Salamon et al. (2011) | **Derived Life-form** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Isotomurus palustris* Gr. | Isot.palu | 56 | 0 | 2 | 0 | 0 | 0 | **0.1** | ep | he | he | | **at** |
| *Tomocerus minor* (Lubbock, 1862) | Tomo.mino | 2 | 0 | 0 | 0 | 0 | 2 | **0.1** | | | he | | **at** |
| *Heteromurus nitidus* (Templeton, 1836) | Hete.niti | 6 | 0 | 2 | 0 | 0 | 2 | **0.2** | | he | eu | he | **at** |
| *Lepidocyrtus cyaneus* (Tullberg, 1871) | Lepi.cyan | 4 | 0 | 2 | 0 | 0 | 2 | **0.2** | ep | at | he | ep | **at** |
| *Lepidocyrtus lanuginosus* (Gmelin, 1788) | Lepi.lanu | 42 | 0 | 2 | 0 | 0 | 2 | **0.2** | ep | at | he | ep | **at** |
| *Lepidocyrtus lignorum* (Fabricius, 1775) | Lepi.lign | 2 | 0 | 2 | 0 | 0 | 2 | **0.2** | | | he | | **at** |
| *Heterosminthurus bilineatus* Gr. | Hete.bili | 2 | 0 | 2 | 0 | 4 | 0 | **0.3** | | at | | | **he** |
| *Lipothrix lubbocki* (Tullberg, 1872) | Lipo.lubb | 2 | 0 | 2 | 0 | 4 | 0 | **0.3** | | | he | | **he** |
| *Pseudosinella alba* (Packard, 1873) | Pseu.alba | 17 | 0 | 4 | 0 | 0 | 4 | **0.4** | he | | eu | he | **he** |
| *Pseudosinella decipiens* (Denis, 1924) | Pseu.deci | 2 | 0 | 4 | 0 | 0 | 4 | **0.4** | | | | | **he** |
| *Pseudosinella denisi* Gisin, 1954 | Pseu.deni | 2 | 0 | 4 | 0 | 0 | 4 | **0.4** | | | | | **he** |
| *Sminthurides malmgreni* (Tullberg, 1876) | Smin.malm | 2 | 0 | 4 | 0 | 4 | 0 | **0.4** | | | | | **he** |
| *Sminthurides parvulus* (Krausbauer, 1898) | Smin.parv | 2 | 0 | 4 | 0 | 4 | 0 | **0.4** | | | he | | **he** |
| *Cryptopygus thermophilus* (Axelson, 1900) | Cryp.ther | 4 | 0 | 4 | 0 | 4 | 2 | **0.5** | | he | he | he | **he** |
| *Desoria tigrina* Gr. | Deso.tigr | 2 | 0 | 4 | 0 | 4 | 2 | **0.5** | | | | | **he** |
| *Deuterosminthurus pallipes* (Bourlet, 1843) | Deut.pall | 27 | 0 | 4 | 0 | 4 | 2 | **0.5** | | at | | ep | **he** |
| *Deuterosminthurus sulphureus* (Koch, 1840) | Deut.sulp | 2 | 0 | 4 | 0 | 4 | 2 | **0.5** | | | | | **he** |
| *Isotoma viridis* Bourlet, 1839 | Isot.viri | 69 | 0 | 4 | 0 | 4 | 2 | **0.5** | ep | he | he | ep | **he** |
| *Parisotoma notabilis* (Schäffer, 1896) | Pari.nota | 56 | 0 | 4 | 0 | 4 | 2 | **0.5** | he | he | | he | **he** |
| *Sminthurinus aureus* Gr. | Smin.aure | 52 | 0 | 4 | 0 | 4 | 2 | **0.5** | he | he | he | ep | **he** |
| *Sminthurinus niger* (Lubbock, 1862) | Smin.nige | 2 | 0 | 4 | 0 | 4 | 2 | **0.5** | | | he | ep | **he** |

**TABLE 4 (PART 2)**

Life-forms (LF) of collembolan species as derived from eco-morphological index (EMI) and publications of Stierhof (2003), Chauvat et al. (2007), Sticht et al. (2008), and Salamon et al. (2011). EMI (eco-morphological index) scores according to Martins da Silva et al. (2016). at: atmobiont; ep: epedaphic; he: hemiedaphic; eu: euedaphic. NA: No data available.
*(Table 4, part 1, see previous page)*

| | Abbreviation | Frequency (%)[a] | Ocelli | Antenna | Furca | Scales/hairs | Pigmentation | **EMI according to Martins da Silva et al. (2016)** | Life-form according to Chauvat et al. (2007) | Life-form according to Sticht et al. (2008) | Life-form according to Stierhof (2003) | Life-form according to Salamon et al. (2011) | **Derived Life-form** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sminthurus viridis* Gr. | Smin.viri | 12 | 0 | 4 | 0 | 4 | 2 | **0.5** | | | | | **he** |
| *Sphaeridia pumilis* (Krausbauer, 1898) | Spha.pumi | 21 | 0 | 4 | 0 | 4 | 2 | **0.5** | he | he | he | he | **he** |
| *Stenacidia violacea* (Reuter, 1881) | Sten.viol | 8 | 0 | 4 | 0 | 4 | 2 | **0.5** | | | | | **he** |
| *Ballistura schoetti* (Dalla Torre, 1895) | Ball.scho | 2 | 0 | 4 | 2 | 4 | 2 | **0.6** | | | | | **he** |
| *Cryptopygus bipunctatus* (Axelson, 1903) | Cryp.bipu | 4 | 0 | 4 | 0 | 4 | 4 | **0.6** | | he | | he | **he** |
| *Parisotoma ekmani* (Fjellberg, 1977) | Pari.ekma | 4 | 0 | 4 | 0 | 4 | 4 | **0.6** | | | | | **he** |
| *Proisotoma minuta* (Tullberg, 1871) | Proi.minu | 48 | 0 | 4 | 2 | 4 | 2 | **0.6** | | he | he | | **he** |
| *Proisotoma tenella* (Reuter, 1895) | Proi.tene | 2 | 0 | 4 | 2 | 4 | 2 | **0.6** | | | | | **he** |
| *Folsomides parvulus* (Stach, 1922) | Fols.parv | 4 | 0 | 4 | 2 | 4 | 4 | **0.7** | | | eu | he | **he** |
| *Proisotoma minima* (Absolon, 1901) | Proi.mini | 2 | 0 | 4 | 2 | 4 | 4 | **0.7** | | | he | | **he** |
| *Xenylla boerneri* Axelson, 1905 | Xeny.boer | 2 | 0 | 4 | 4 | 4 | 2 | **0.7** | | | | | **he** |
| *Cryptopygus garretti* (Bagnall, 1939) | Cryp.garr | 4 | 4 | 4 | 0 | 4 | 4 | **0.8** | | | | | **eu** |
| *Cyphoderus albinus* Nicolet, 1842 | Cyph.albi | 10 | 4 | 4 | 0 | 4 | 4 | **0.8** | he | | eu | | **eu** |
| *Isotomiella minor* (Schäffer, 1896) | Isot.mino | 33 | 4 | 4 | 0 | 4 | 4 | **0.8** | eu | eu | eu | | **eu** |
| *Magalothorax minimus* Willem, 1900 | Mega.mini | 2 | 4 | 4 | 0 | 4 | 4 | **0.8** | eu | eu | eu | | **eu** |
| *Oncopodura crassicornis* Shoebotham, 1911 | Onco.cras | 4 | 4 | 4 | 0 | 4 | 4 | **0.8** | | | eu | | **eu** |
| *Folsomia candida* Willem, 1902 | Fols.cand | 4 | 4 | 4 | 2 | 4 | 4 | **0.9** | | he | eu | | **eu** |
| *Folsomia spinosa* Kseneman, 1936 | Fols.spin | 2 | 4 | 4 | 2 | 4 | 4 | **0.9** | | he | eu | | **eu** |
| *Isotomodes productus* (Axelson, 1906) | Isot.prod | 10 | 4 | 4 | 2 | 4 | 4 | **0.9** | | eu | eu | eu | **eu** |
| *Mesaphorura* sp. | Mesa.spec | 21 | 4 | 4 | 4 | 4 | 4 | **1** | | | | | **eu** |
| *Neotullbergia crassicuspis* (Gisin, 1944) | Neot.cras | 2 | 4 | 4 | 4 | 4 | 4 | **1** | | eu | eu | | **eu** |
| *Paratullbergia callipygos* (Börner, 1902) | Para.call | 2 | 4 | 4 | 4 | 4 | 4 | **1** | eu | eu | eu | | **eu** |
| *Protaphorura armata* Gr. | Prot.arma | 27 | 4 | 4 | 4 | 4 | 4 | **1** | eu | | eu | eu | **eu** |
| *Stenaphorura denisi* Bagnall, 1935 | Sten.deni | 8 | 4 | 4 | 4 | 4 | 4 | **1** | eu | eu | eu | eu | **eu** |
| *Supraphorura furcifera* (Börner, 1901) | Supr.furc | 2 | 4 | 4 | 4 | 4 | 4 | **1** | | | | | **eu** |
| *Willemia anophthalma* (Börner, 1901) | Will.anop | 6 | 4 | 4 | 4 | 4 | 4 | **1** | eu | eu | eu | eu | **eu** |

[a] Frequency in % from a total of 48 samples.

type. The use of 0.7 as upper threshold for the hemiedaphic type is supported by studies of Dittmer and Schrader (2000), Salamon et al. (2004), and Querner (2008). Additionally, this threshold separates species with and without ocelli. Studies by Caravaca and Ruess (2014), D'Annibale et al. (2015), Dombos et al. (2017), Gillet and Ponge (2004), Leinaas and Bleken (1983), Lindberg and Bengtsson (2005), Ponge (2000), and Sterzynska and Kuznetsova (1995) justify separation between hemiedaphic and atmobiont at 0.3. As we followed the system proposed by Gisin (1943) we combined species described as epigeic and atmobiont under the term atmobiont.

## 2.5 Statistics

### 2.5.1 Statistical models

Generalised linear mixed models (GLMMs) were used including 'crop rotation' (LI *versus* SL) as fixed effect and 'field-code' (unique to each field on the experimental station) as random intercept effect for detecting differences in collembolan abundance or species richness depending on the type of crop rotation. The 'tillage regime' (CT *versus* RT) was used as fixed effect in GLMM when analysing the influence of tillage on collembolan abundance. 'Sampling date' (May 2012, May 2014) and the interaction of 'sampling date' and 'tillage regime' were used as additional fixed effects to check for temporal variability within the data. The 'crop rotation' (L I, L II, L III) was used as random intercept effect. The same set-up was used when modelling collembolan species richness depending on differences in the tillage regime.

Mean trait values (EMI mT-values) were evaluated using linear mixed models (LMMs). The model evaluating the influence of 'crop rotation' used 'crop rotation' (L I *versus* SL) as fixed effect and 'field-code' as random intercept effect. After applying a backward selection procedure, the model describing the influence of 'tillage regime' on EMI mT-values used 'sampling date' (May 2012, May 2014) as fixed effect and 'crop rotation' (L I, L II, L III) as random intercept effect.

Statistical analyses were conducted using R 3.2.2 (R Development Core Team, 2016). All GLMMs were calculated for negative-binomial distributed count data. We used the R-package glmmADMB (Skaug et al., 2015) for calculating GLMMs. For negative-binomial models the package uses the log as standard link-function. The estimation method used in glmmADMB is Laplace. Linear mixed models were calculated using the R-package lme4 (Bates et al., 2015). After setting up models LS-Means and pairwise comparisons were obtained using the R-package lsmeans (Lenth, 2016). Abundance, species richness and EMI mT-values presented in the results section are LS-means.

#### 2.5.2 Non-metric multidimensional scaling (NMDS)

Non-metric multidimensional scaling (NMDS) and associated analyses were conducted using the R-package vegan (Oksanen et al., 2015). After conducting NMDS, differences between centroids for factor levels were analysed using permutational multivariate analysis of variance using distance matrices (R-function vegan::adonis). Homogeneity of multivariate spread is a prerequisite for comparing centroids and was therefore checked in advance (R-function vegan::betadisper). The adjustment of p-values obtained from pairwise comparisons of centroids was conducted using Bonferroni correction. NMDS were calculated using abundance values and used Bray-Curtis as dissimilarity measure. The final NMDS analysis for the comparisons between crop rotations and tillage regimes both used three dimensions and had stress values of twelve and eleven, respectively. When displaying species in the NMDS plots they had to be weighted. Only the main species were displayed to avoid overlapping of species labels. Species weighting was done as follows: (1) calculating the share of each species in every sample; (2) calculating the share of samples in which the share of a species was greater than or equal to 3.2 %; (3) weighting of species according to this share of samples. The threshold of 3.2 % was chosen according to Engelmann (1978) who proposed this level for separation of main and other species of soil arthropod communities.

#### 2.5.3 Ternary diagrams

Ternary diagrams illustrate compositions of three components and we used them to visualise the composition of collembolan life-forms. We calculated the relative share of atmobiont, hemiedaphic, and euedaphic collembolan individuals for each sample. For creating ternary diagrams the R-package compositions was used (van den Boogaart et al., 2014). The share of each component is 100 % in the corner labelled accordingly and 0 % at the line opposite to that corner.

## 3 Results and discussion

### 3.1 Abundance, species richness and life-forms

Overall, 47 collembolan species and species groups were identified within the samples analysed for this study (*Table 4*). Based on their occurrence in the samples of this dataset seven species are rated eudominant, eight dominant, 12 subdominant and 20 as rare according to Engelmann (1978).

#### 3.1.1 Comparison of crop rotations: livestock I *versus* stockless

In May 2012, after 10 years of different crop rotation management treatments, neither collembolan abundance nor species richness differed significantly between the two crop rotations livestock I (L I) and stockless (SL) (*Table 5*). On fields of the L I rotation, 22 species and on fields of the SL rotation 29 species were identified. While not significant, collembolan abundance, the overall number of species, and the number of species per sample were higher in the stockless rotation. These trends found in our study are in line with results of studies conducted by Kautz et al. (2006) and Pommeresche et al. (2017). Kautz et al. (2006) found a positive effect of regular application of straw and green manure on overall collembolan abundance which they attributed to improved soil physical properties and good food supply. In addition, Pommeresche et al. (2017) observed a decrease in collembolan abundance after slurry application, which was more pronounced for epigeic than for endogeic collembolan species. According to Domene et al. (2010), this negative effect of manuring can be ascribed to extractable ammonium from the slurry which is toxic for collembolans. Within our study, a higher proportion of plant residues remained on the fields of the stockless rotation while the fields of the livestock I rotation were regularly manured with slurry (cf. *Table 2*).

TABLE 5
Results of statistical modelling (GLMM) to reveal the influence of different crop rotations (L I vs. SL) on abundance and species richness of collembolans (n=24). Least square means (LSM) as well as lower (LCL) and upper (UCL) confidence levels are given.

| Response | p | Effect level | LSM | Asymptotic LCL | Asymptotic UCL |
|---|---|---|---|---|---|
| Abundance (Individuals $m^{-2}$) | 0.4384 | L I | 19,126 | 8,015 | 45,645 |
| | | SL | 31,107 | 13,033 | 74,244 |
| Species richness (Species per sample) | 0.2131 | L I | 5 | 3 | 7 |
| | | SL | 7 | 5 | 10 |

There was no significant difference between EMI mT-values of the two crop rotations in May 2012 (L I: 0.51 ± 0.06; SL: 0.55 ± 0.06; p=0.6452). When visually comparing the proportions of life-forms between L I and SL fields, a higher relative share of euedaphic individuals under L I could be revealed, while the relative share of hemiedaphic individuals was higher under SL (*Figure 3*). Because the 95 % CIs overlap these differences are considered as not significant. The trend towards higher relative share of euedaphic individuals in the livestock I rotation may be caused by negative effects of regular slurry application on surface dwelling collembolans (Pommeresche et al., 2017).

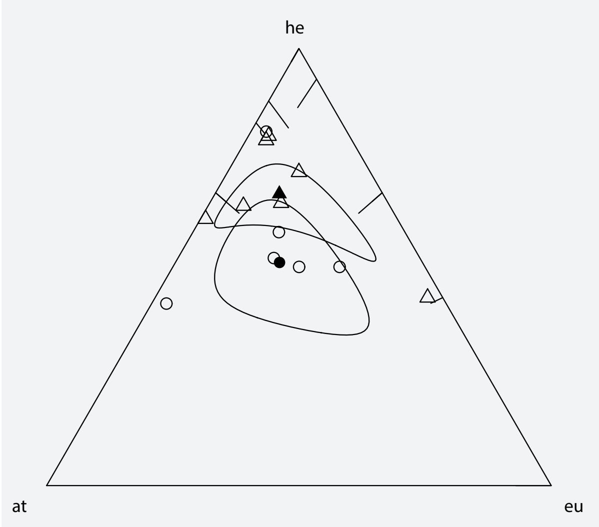


FIGURE 3

Ternary diagram representing the relative proportions of life-forms (eu: euedaphic, he: hemiedaphic, at: atmobiont) in the collembolan communities on the fields of the livestock I (L I) and stockless (SL) rotation in 2012. Data from SL marked with triangles and data from L I with circles. Solid markings represent the geometrical means. In addition 95 % CI are shown.

### 3.1.2 Comparison of tillage regimes: conventional *versus* reduced

No significant differences in collembolan abundance or species richness were observed in either 2012, before setting aside the plough, or in 2014, after two years of different tillage regimes in place when comparing conventional tillage (CT) and reduced tillage (RT) (*Table 6*). Furthermore, there was no significant interaction between tillage regime and year of sampling.

As in our study, Petersen (2002) did not find any difference in collembolan abundance when comparing conventional tillage with ploughing and non-inverting deep tillage in a one-year case study. Sabatini et al. (1997) support this result for the long run when studying fields constantly managed with three different tillage intensities for 15 years prior to sampling. In contrast, Miyazawa et al. (2002) revealed a positive effect of reduced tillage on collembolan abundance. The fact that we did not observe any differences between

TABLE 6

Results of statistical modelling (GLMM) to reveal the influence of different tillage regimes (CT vs. RT) on abundance and species richness of collembolans (n=24). Least square means (LSM) as well as lower (LCL) and upper (UCL) confidence levels are given.

| Response | Grouping | p | Effect Level | LSM | Asymptotic LCL | Asymptotic UCL |
|---|---|---|---|---|---|---|
| Abundance (Individuals $m^{-2}$) | 2012 | 0.0514 | CT | 8,220 | 5,317 | 12,708 |
| | | | RT | 12,046 | 7,762 | 18,693 |
| | 2014 | 0.4821 | CT | 29,067 | 18,804 | 44,933 |
| | | | RT | 25,357 | 16,419 | 39,161 |
| | CT | **<0.0001** | 2012 | 8,220 | 5,317 | 12,708 |
| | | | 2014 | 29,067 | 18,804 | 44,933 |
| | RT | **0.0002** | 2012 | 12,046 | 7,762 | 18,693 |
| | | | 2014 | 25,357 | 16,419 | 39,161 |
| Species number (Species per sample) | 2012 | 0.8995 | CT | 5 | 3 | 8 |
| | | | RT | 5 | 3 | 8 |
| | 2014 | 0.8206 | CT | 6 | 4 | 10 |
| | | | RT | 6 | 4 | 9 |
| | CT | 0.2881 | 2012 | 5 | 3 | 8 |
| | | | 2014 | 6 | 4 | 10 |
| | RT | 0.476 | 2012 | 5 | 3 | 8 |
| | | | 2014 | 6 | 4 | 9 |

conventional and reduced tillage could be due to our use of a rather intensive form of reduced tillage with the use of chisel plough and rotary harrow. In addition, the sampling in May 2014 took place nine months after the last ploughing and the time might have been long enough for the collembolan communities to recover from this disturbance (Petersen, 2002). Furthermore, the influence of soil tillage on collembolan abundance is mediated by abiotic soil properties. When evaluating twelve datasets from nine German studies van Capelle et al. (2012) showed an overall positive effect of conventional tillage on collembolan abundance and diversity, but also highlighted that this overall effect did not hold true for all combinations of soil type and life-forms. For instance, species of all life-forms were promoted by reduced tillage and not by conventional tillage in silty soils.

In our study collembolan abundance was significantly higher in May 2014 as compared to May 2012 under both tillage regimes. We ascribe this result to higher soil moisture in 2014 and the different crops under study in 2012 (spring grown grain-legume cereal mixtures or pure grain-legumes) and in 2014 (winter grown clover-grass). Seasonal effects on collembolan communities based on differences in soil moisture rather than on differences in management were also shown by D'Annibale et al. (2017). Due to the setup of our investigating it was not possible to distinguish the effect of year and cultivated crops, but we could show that there was no effect of tillage regime on collembolan abundance or species richness in our study.

A visual comparison of the proportions of life forms under CT and RT in May 2012 (*Figure 4a*) and May 2014 (*Figure 4b*) was possible using ternary diagrams. There was no difference in the proportions of life forms in May 2012. In May 2014, the relative share of atmobiont individuals was higher under CT than under RT whereas under RT the relative share of hemiedaphic individuals was higher (*Figure 4b*). The 95 % CIs only overlap slightly for the data from May 2014.

Martins da Silva et al. (2016) found an increase in euedaphic collembolans in soil habitats offering stable conditions in terms of resource availability, soil moisture, or disturbance in a Europe-wide study of different habitat types (forests, grasslands, arable land). Therefore, we hypothesise that the trend towards a higher relative share of hemiedaphic individuals after two years of reduced tillage indicates the early stages of the stabilisation of habitat conditions on the field-halves that were not ploughed.

Irrespective of the tillage regime, the EMI mT-value was significantly higher in May 2012 than in May 2014 (2012: 0.61 ± 0.04; 2014: 0.44 ± 0.04; p<0.01). Higher EMI mT-values indicate a higher relative share of euedaphic individuals, which we assume is due to the dry weather conditions in 2012 decreasing the relative share of hemiedaphic and atmobiont individuals.

## 3.2 Collembolan communities

In the following we use autecological information on collembolan species to characterise gradients uncovered with multivariate statistical methods. This approach must take geographical differences into account. Fjellberg (1998, 2007) characterises *Protaphorura armata* and *Sminthurus viridis* as preferring rather dry or mostly dry habitats. This is contrary to the views of other authors. While Hopkin (1997) reports that *P. armata* is susceptible to drought, Bretfeld (1999) states that *S. viridis* prefers the vegetation of moister grasslands and herbaceous fields. We suppose that these different ratings of

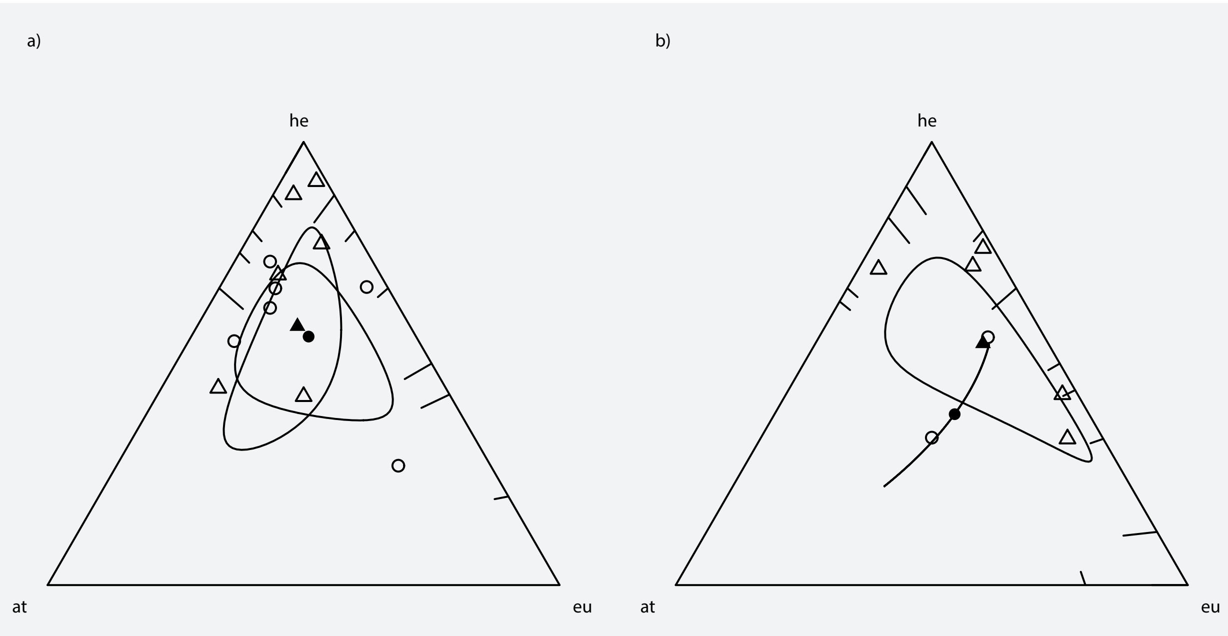


FIGURE 4

Ternary diagram representing the relative proportions of life-forms (eu: euedaphic, he: hemiedaphic, at: atmobiont) in the collembolan communities on the fields under CT and RT in May 2012 (a) and May 2014 (b). Data from RT marked with triangles and data from CT with circles. Solid markings represent the geometrical means. In addition 95 % CI are shown.

species are due to the fact that the assessments of Fjellberg (1998, 2007) are more valid for boreal and alpine regions with lower mean temperatures. Individuals of the same collembolan species are able to tolerate different humidity levels depending on the mean temperatures in their respective habitat, with individuals living in colder habitats tolerating lower humidity (Snider and Butcher, 1972, as cited in Hopkin 1997). Therefore, in the case of *P. armata* and *S. viridis* we adopted the view of Hopkin (1997) and Bretfeld (1999), respectively.

### 3.2.1 Comparison of crop rotations: livestock I *versus* stockless

In May 2012 the main gradient within the data on collembolan communities from the livestock I (L I) and the stockless (SL) rotation along the first NMDS-axis is spanned by *Protaphorura armata* Group and *Sphaeridia pumilis* and the gradient along the second axis was spanned by *Heterosminthurus bilineatus* Group and *Pseudosinella decipiens* on the one end and *Willemia anophthalma* on the other end of the axis (*Figure 5a*).

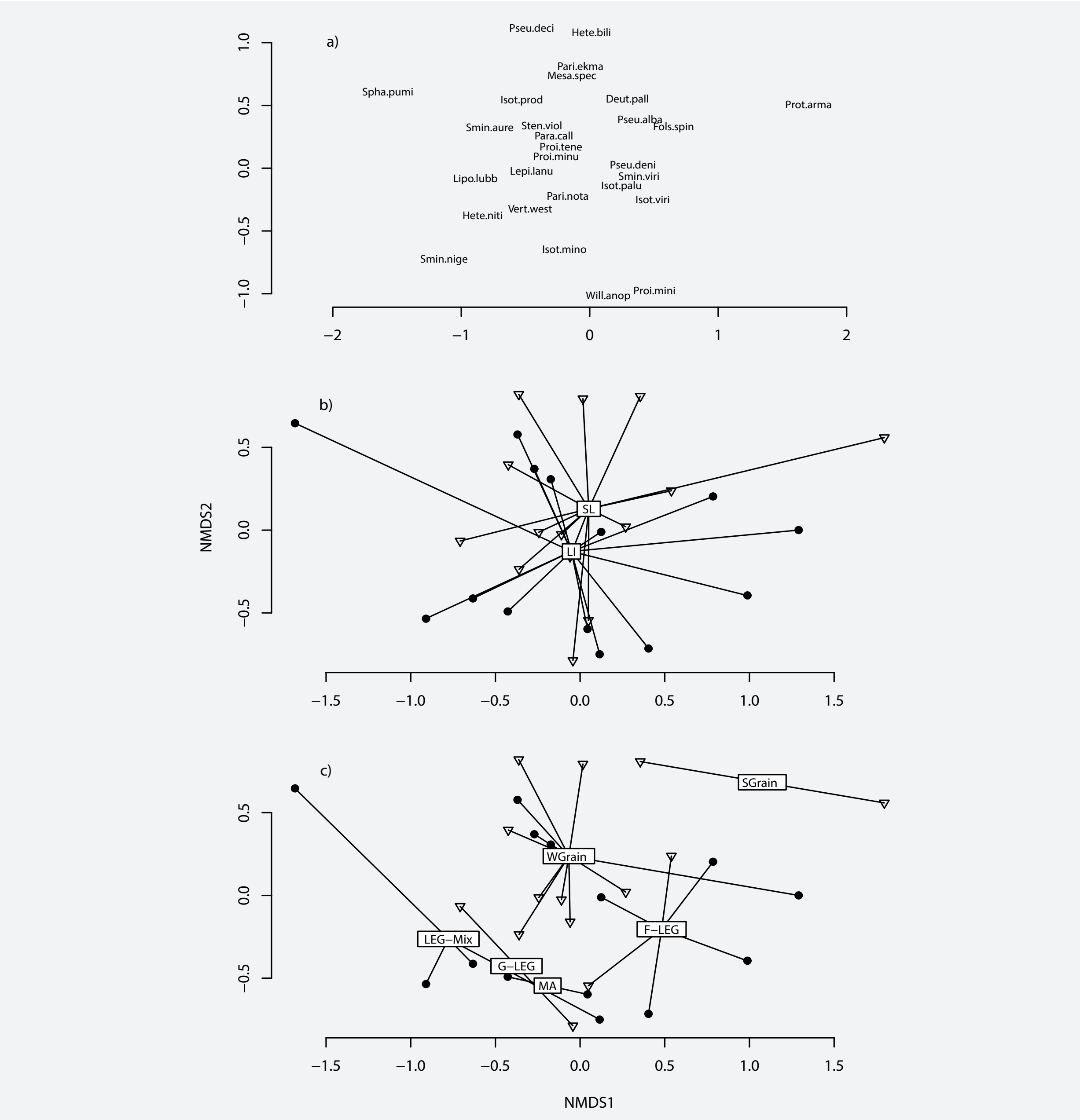


FIGURE 5
NMDS for the collembolan data from May 2012 for the two crop rotations livestock I (L I) and stockless (SL).
a) Ordination showing main species within the dataset (abbreviations according to Table 4).
b) Sampling points grouped according to farming systems (SL marked with triangles and LI with circles).
c) Sampling points grouped according to crop classes (SGrain: spring grown grain; WGrain: winter grown grain; F-LEG: fodder legumes (clover-grass mixture); G-LEG: grain legumes; LEG-Mix: mixtures of grain legumes and grains; MA: maize).

No significant difference between the centroids for the two crop rotations (L I *versus* SL) were identified (p=0.105). It is clear that there is no difference along the first axis and only little difference along the second axis (*Figure 5b*). When using crop-classes rather than crop rotations as grouping variables some differentiation is possible (*Figure 5c*). Collembolan communities differ between autumn-sown and spring-sown crops. However, none of the centroids differ significantly (*Table 7*).

The species spanning axis 1 can be differentiated according to their life-forms. *P. armata* is an euedaphic species, a "true soil-dweller" (Bauer and Christian, 1993), with only poor drought resistance (Hopkin, 1997). On the other hand, *S. pumilis* lives in the litter layer of soils of different humidity levels (Bretfeld, 1999; Ponge, 2000) and is a mobile epigeic species (Salamon et al., 2004). As the centroids of the livestock I and stockless rotation were not separated along this axis, both crop rotations host collembolan communities consisting of a balanced mixture of species of different life-forms after ten consistent years of different organic farming practices.

The second axis could follow a gradient of soil acidity. *P. decipiens* is characterised as not occurring under acid conditions (Ponge, 1993), while *W. anophthalma* prefers acidic habitats like peat, mor, or moder (Chauvat and Ponge, 2002; Salmon et al., 2014). Therefore, we hypothesise that the data on collembolan communities indicate more acidic conditions under the livestock I rotation than under the stockless rotation.

TABLE 7

Results of pairwise comparison of centroids from NMDS from the collembolan dataset in L I and SL in May 2012.

| | adjusted p |
|---|---|
| F-LEG–G-LEG | 1 |
| F-LEG–LEG-Mix | 0.9 |
| F-LEG–MA | NA |
| F-LEG–SGrain | 0.675 |
| F-LEG–WGrain | 0.345 |
| G-LEG–LEG-Mix | NA |
| G-LEG–MA | NA |
| G-LEG–SGrain | NA |
| G-LEG –WGrain | 1 |
| G-LEG-Mix–MA | NA |
| LEG-Mix–SGrain | NA |
| LEG-Mix–WGrain | 1 |
| MA - SGrain | NA |
| MA–WGrain | NA |
| SGrain–WGrain | 0.285 |

SGrain: spring grown grain; WGrain: winter grown grain;
F-LEG: fodder legumes (clover-grass mixture); G-LEG: grain legumes;
LEG-Mix: mixtures of grain legumes and grains; MA: maize.

NA: Comparison of centroids were not possible as homogeneity of multivariate spread could not be achieved.

The differentiation between collembolan communities of different crop classes was more pronounced. Differences became apparent between autumn-sown and spring-sown crops along axis 1. As sampling took place in May, the time elapsed since tillage and sowing differed markedly between these two groups. Different crops were in different development stages causing different degrees of soil coverage. As Salmon et al. (2014) found convergence of collembolan species traits for epigeic species and those living in open habitats, the gradient along the first axis could reflect differences in habitat openness. Along the second axis, legumes and maize can be differentiated from cereals. Here the collembolan communities might uncover lower pH values in the rhizosphere of legumes and maize (Kamh et al., 2002; Maltais-Landry, 2015). Kamh et al. (2002) found enhanced release of protons from Zea mays under P-deficient conditions. To what extent proton release of young maize plants to dissolve phosphorus influenced soil pH was not within the scope of our study, but cannot be ruled out as a mechanism influencing habitat conditions for soil fauna on the study site (Ohm et al., 2015). Therefore, the higher relative share of legumes and maize in the livestock I rotation (cf. *Table 1*) could have influenced the differentiation of the livestock I and stockless rotation along the second NMDS-axis.

### 3.2.2 Comparison of tillage regimes: conventional *versus* reduced

The first axis of an NMDS on the collembolan data from fields under conventional (CT) and reduced (RT) tillage is spanned by *Sminthurides malmgreni*, *Cyphoderus albinus* and *Pseudosinella alba* on the one end and *Deuterosminthurus pallipes* and *Neotullbergia crassicuspis* on the other end of the axis (*Figure 6* a). NMDS-axis 2 is spanned by *Sminthurides parvulus*, *P. armata* Group, *Supraphorura furcifera* and *Isotomurus palustris* Group on the one end and *P. alba*, *Cryptopygus thermophilus* and *Sminthurinus niger* on the other end of the axis.

Species at both ends of the first NMDS-axis are xerothermophil and prefer dry and open habitats (*C. albinus* (Bockemühl, 1956, as cited in Dekoninck et al., 2007), *P. alba* (Filser, 1995), *D. pallipes* (Bretfeld, 1999; Fjellberg, 2007; Querner, 2004), *N. crassicuspis* (Stierhof, 2003)). Along the second axis, a humidity gradient seems to be spanned. *S. parvulus*, *P. armata*, *S. furcifera*, and *I. palustris* prefer wet or damp habitats (Bretfeld, 1999; Fjellberg, 1998, 2007; Hopkin, 1997, 2007) whereas *P. alba* and *C. thermophilus* are adapted to dry habitat conditions (Detsis, 2009; Filser, 1995; Kautz et al,. 2006; Potapov, 2001).

There was no difference between centroids of CT and RT in May 2012 and in May 2014 (figure not shown). The lack of differences between conventional and reduced tillage in 2014, after two years of different management treatments, could be due to the intensive form of reduced tillage investigated in this study (cf. 3.1.2) or due to sampling of collembolans taking place nine months after the last soil tillage, so that collembolan communities may have aligned during this time. Although the centroids differed between May 2012 and May 2014 (*Figure 6b*), no test for significance of this difference was possible as the condition of homogeneity of multivariate spread was not satisfied. Significant differences between spring grain crops (grain-legume/cereal mixtures; LEG-Mix) and fodder legumes (red clover-grass; F-LEG) (p=0.003) and between grain legumes (G-LEG) and fodder legumes (F-LEG) (p=0.003) could be shown (*Figure 6c*).

In May 2012, all fields were cultivated with grain legumes or with grain-legume/cereal mixtures, respectively. In May 2014, all fields were cultivated identically with fodder legumes. Therefore, effect of year and crop class cannot be separated in our analyses (cf. 3.1.2). However, we could show that there were no differences between collembolan communities based on tillage regimes and furthermore hypothesise that differences between data from May 2012 and May 2014 are related to differences in soil moisture.

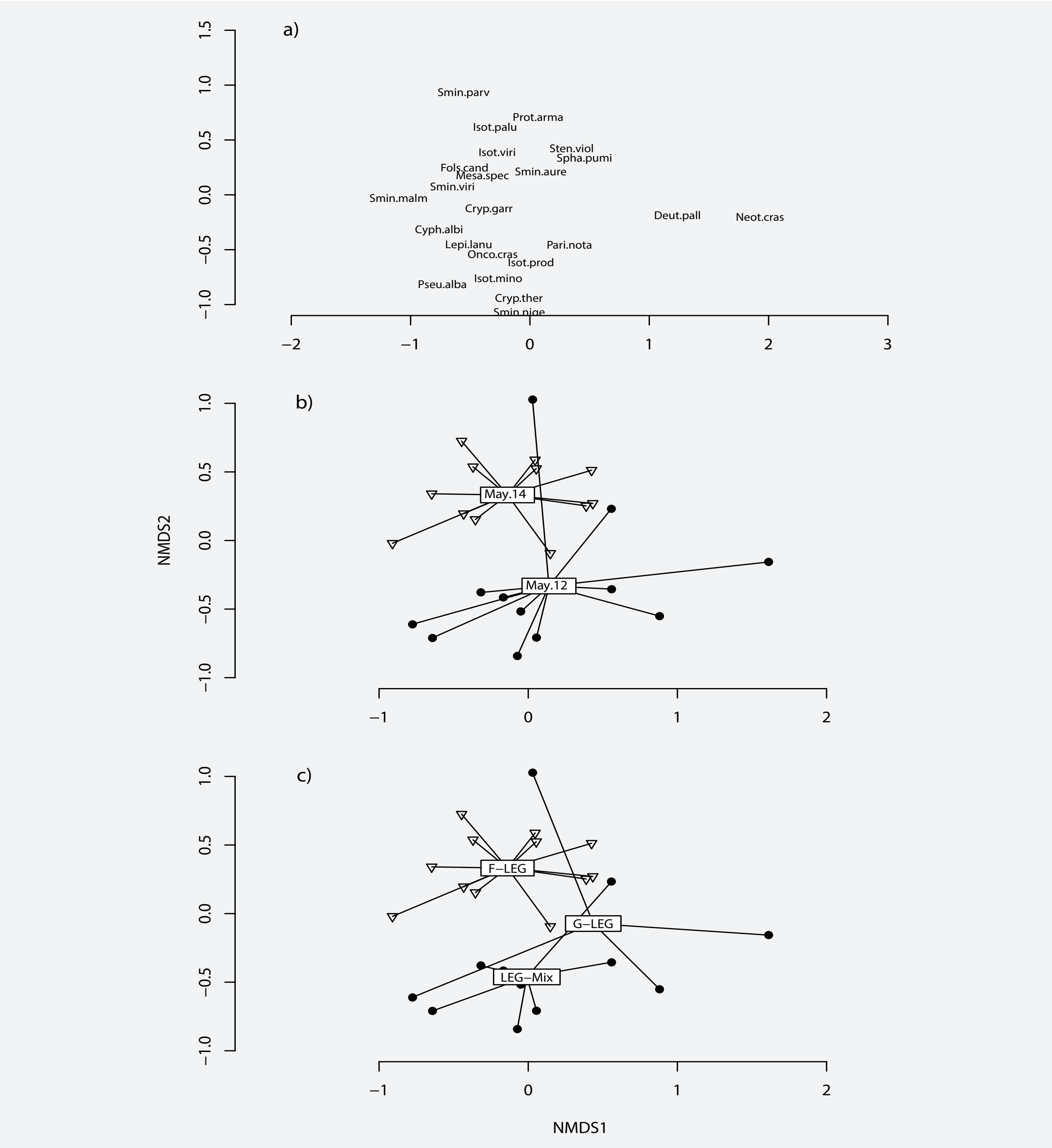


**FIGURE 6**

NMDS for the collembolan data from May 2012 and May 2014 under the different management systems CT (conventional tillage) and RT (reduced tillage).

a) Ordination showing main species within the dataset (abbreviations according to Table 4).

b) Sampling points grouped according to sampling month (May 2012 marked with triangles and May 2014 with circles).

c) Sampling points grouped according to crop classes (F-LEG: fodder legumes (clover-grass mixture); G-LEG: grain legumes; LEG-Mix: mixtures of grain legumes and grains).

While in 2012 spring grown crops were cultivated the grass-clover-mixture present on all fields in 2014 was a winter-grown crop. Thus, higher soil cover of the vegetation in May 2014 may have led to higher soil moisture. Alvarez et al. (2001) also discussed a positive effect of higher soil moisture due to higher weed densities as possibly influencing collembolan communities. Furthermore, data from the German Weather Service (DWD) on soil moisture revealed overall higher water content in the soil in 2014 (*Figure 2*).

## 4 Conclusion

Neither different crop rotations kept over ten years nor shorter-term changes in tillage regimes significantly influenced collembolan abundance, species richness, EMI mT-values, or collembolan species composition at this experimental station. We found that collembolan abundance and species composition reacted to intermingled effects of different crops cultivated with interannual variability. However, shifts in the relative share of the different collembolan life-forms showed some non-significant reactions to management differences. The relative share of euedaphic individuals is of particular interest, as some previous studies show that their proportion can be used as an indicator for stable soil habitat conditions. For different crop rotations, we found some first evidence that soil habitats in organic farming systems with regular manuring and a high share of green fodder crops (here clover-grass mixtures) tend to be more stable than those in systems without high input of manure and a low share of green-fodder crops.

The results of this study are of interest not just for the further development of organic arable farming systems. As techniques such as increasing crop rotation diversity and reducing tillage intensity are discussed also for non-organic farming systems, under the keywords agroecology (Tomlinson, 2013) or ecological intensification (Kleijn et al., 2019), their evaluation is of broader interest for any farming system aiming to implement sustainable management regimes.

## Acknowledgements

We thank Daniel Baumgart, Regina Grünig, Magdalena Langer, Rainer Legrand and Meike Reimann for active support in the preparation of collembolan samples. In addition, we would like to thank two anonymous reviewers for valuable comments on the manuscript of this paper.

### REFERENCES

Alvarez T, Frampton GK, Goulson D (2001) Epigeic Collembola in winter wheat under organic, integrated and conventional farm management regimes. Agric Ecosyst Environ 83(1–2):95–110, doi:10.1016/S0167-8809(00)00195-X

Andrén O, Lagerlöf J (1983) Soil Fauna (Microarthropods, Enchytraeids, Nematodes) in Swedish agricultural cropping systems. Acta Agric Scand 33(1): 33–52, doi:10.1080/000–5128309435350

ASABE (2009) ASAE S414.2: Terminology and definitions for agricultural tillage implements [online]. St. Joseph, Michigan: American Society of Agricultural and Biological Engineers. Retrieved from <https://elibrary.asabe.org/abstract.asp?aid=44205&t=2> [at 23 Dec 2020]

ASAE (2005) ASAE EP291.3: Terminology and definitions for soil tillage and soil-tool relationships [online]. St. Joseph, Michigan: American Society of Agricultural Engineers. Retrieved from <https://prod.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_053410.pdf> [at 23 Dec 2020]

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67(1):1-48, doi:10.18637/jss.v067.i01

Bauer R, Christian E (1993) Adaptations of three springtail species to granite boulder habitats (Collembola). Pedobiologia 37:280–290

Blume HP, Brümmer GW, Horn R, Kandeler E, Kögel-Knabner I, Kretschmar R, Stahr K, Wilke BM (2010) Scheffer/Schachtschabel. Lehrbuch der Bodenkunde. 16th edition. Heidelberg: Spektrum Akademischer Verlag, 569 p

Brennan A, Fortune T, Bolger T (2006) Collembola abundances and assemblage structures in conventionally tilled and conservation tillage arable systems. Pedobiologia 50(2):135–145, doi:10.1016/j.pedobi.2005.09.004

Bretfeld G (ed) (1999) Symphypleona. Görlitz: Staatliches Museum für Naturkunde Görlitz, 320 p, Synopses on Palaearctic Collembola 2

Caravaca F, Ruess L (2014) Arbuscular mycorrhizal fungi and their associated microbial community modulated by Collembola grazers in host plant free substrate. Soil Biol Biochem 69:25–33, doi:10.1016/j.soilbio.2013.10.032

Chauvat M, Ponge JF (2002) Colonization of heavy metal-polluted soils by collembola: preliminary experiments in compartmented boxes. Appl Soil Ecol 21(2):91–106, doi:10.1016/S0929-1393(02)00087-2

Chauvat M, Wolters V, Dauber J (2007) Response of collembolan communities to land-use change and grassland succession. Ecography 30(2):183–192, doi:10.1111/j.0906-7590.2007.04888.x

D'Annibale A, Larsen T, Sechi V, Cortet J, Strandberg B, Vincze É, Filser J, Audisio PA, Krogh PH (2015) Influence of elevated $CO_2$ and GM barley on a soil mesofauna community in a mesocosm test system. Soil Biol Biochem 84:127–136, doi:10.1016/j.soilbio.2015.02.009

D'Annibale A, Sechi V, Larsen T, Christensen S, Krogh PH, Eriksen J (2017) Does introduction of clover in an agricultural grassland affect the food base and functional diversity of Collembola? Soil Biol Biochem 112:165–176, doi:10.1016/j.soilbio.2017.05.010

Dekoninck W, Lock K, Janssens F (2007) Acceptance of two native myrmecophilous species, *Platyarthrus hoffmannseggii* (Isopoda: Oniscidea) and *Cyphoderus albinus* (Collembola: Cyphoderidae) by the introduced invasive garden ant *Lasius neglectus* (Hymenoptera: Formicidae) in Belgium. Eur J Entomol 104(1):159–161, doi:10.14411/eje.2007.023

Detsis V (2009) Relationships of some environmental variables to the aggregation patterns of soil microarthropod populations in forests. Eur J Soil Biol 45(5–6):409–416, doi:10.1016/j.ejsobi.2009.06.007

Dittmer S, Schrader S (2000) Longterm effects of soil compaction and tillage on Collembola and straw decomposition in arable soil. Pedobiologia 44(3–4):527–538, doi:10.1078/S0031-4056(04)70069-4

Dombos M, Kosztolányi A, Szlávecz K, Gedeon C, Flórián N, Groó Z, Dudás P, Bánszegi O (2017) EDAPHOLOG monitoring system: automatic, real-time detection of soil microarthropods. Methods Ecol Evol 8(3):313–321, doi:10.1111/2041-210X.12662

Domene X, Colón J, Uras MV, Izquierdo R, Àvila A, Alcañiz JM (2010) Role of soil properties in sewage sludge toxicity to soil collembolans. Soil Biol Biochem 42(11):1982–1990, doi:10.1016/j.soilbio.2010.07.019

Dunger W, Schlitt B (2011) Tullbergiidae. Görlitz: Staatliches Museum für Naturkunde Görlitz, 168 p, Synopses on Palaearctic Collembola 6/1

Eisenhauer N (2016) Plant diversity effects on soil microorganisms: Spatial and temporal heterogeneity of plant inputs increase soil biodiversity. Pedobiologia 59(4):175–177, doi:10.1016/j.pedobi.2016.04.004

Engelmann H-D (1978) Zur Dominanzklassifizierung von Bodenarthropoden. Pedobiologia 18:378–380

Filser J (1995) The effect of green manure on the distribution of collembola in a permanent row crop. Biol Fertil Soils 19(4):303–308, doi:10.1007/BF00336099

Fjellberg A (1998) The Collembola of Fennoscandia and Denmark. Part I: Poduromorpha. Leiden, Boston, Köln: Brill, 184 p, Fauna Entomologica Scandinavica

Fjellberg A (2007) The Collembola of Fennoscandia and Denmark. Part II: Entomobryomorpha and Symphypleona. Leiden, Boston: Brill, 266 p, Fauna Entomologica Scandinavica 42, doi:10.1163/ej.9789004157705.i-265

Gillet S, Ponge JF (2004) Are acid-tolerant Collembola able to colonise metal-polluted soil? Appl Soil Ecol 26(3):219–231, doi:10.1016/j.apsoil.2004.01.001

Gisin H (1943) Ökologie und Lebensgemeinschaften der Collembolen im schweizerischen Exkursionsgebiet Basels. Rev Suisse Zool 50:131–224

Gisin H (1960) Collembolenfauna Europas. Geneve: Museum d'Histoire Naturelle

Greenslade P (2007) The potential of Collembola to act as indicators of landscape stress in Australia. Aust J Exp Agric 47(4):424–434, doi:10.1071/EA05264

Haneklaus S, Paulsen H, Schröder D, Leopold U, Schnug E (1998) Self-surveying: a strategy for efficient mapping of the spatial variability of time constant soil parameters. Commun Soil Sci Plant Anal 29(11–14):1593–1601; doi:10.1080/00103629809370052

Hopkin SP (1997) Biology of the Springtails (Insecta: Collembola). Oxford University Press, 344 p

Hopkin SP (2007) A Key to the Collembola (Springtails) of Britain and Ireland. Shrewsbury: Preston Montford, Field Studies Council, AIDGAP

Jagers Op Akkerhuis G, De Ley F, Zwetsloot H, Ponge JF, Brussaard L (1988) Soil microarthropods (Acari and Collembola) in two crop rotations on a heavy marine clay soil. Revue d'Ecologie et de Biologie du Sol 25(2): 175–202

Jeffery S, Gardi C, Jones A, Montanarella L, Marmo L, Miko L, Ritz K, Peres G, Römbke J, van der Putten WH (eds) (2010) European atlas of soil biodiversity. Luxembourg: European Commission, Publications Office of the European Union, 128 p, doi:10.2788/94222

Jordana R (2012) Capbryinae & Entomobryini. Görlitz: Staatliches Museum für Naturkunde Görlitz, 390 p, Synopses on Palaearctic Collembola 7/1

Kamh M, Abdou M, Chude V, Wiesler F, Horst WJ (2002) Mobilization of phosphorus contributes to positive rotational effects of leguminous cover crops on maize grown on soils from northern Nigeria. J Plant Nutr Soil Sci 165(5):566–572, doi:10.1002/1522-2624(200210)165:5<566::AID-JPLN566>3.0.CO;2-O

Kanal A (2004) Effects of fertilisation and edaphic properties on soil-associated Collembola in crop rotation. Agron Res 2(2):153-168

Kautz T, López-Fando C, Ellmer F (2006) Abundance and biodiversity of soil microarthropods as influenced by different types of organic manure in a long-term field experiment in Central Spain. Appl Soil Ecol 33(3):278–285, doi:10.1016/j.apsoil.2005.10.003

Kleijn D, Bommarco R, Fijen TPM, Garibaldi LA, Potts SG, van der Putten WH (2019) Ecological intensification: Bridging the gap between science and practice. Trends Ecol Evol 34(2):154–166, doi:10.1016/j.tree.2018.11.002

Leinaas HP, Bleken E (1983) Egg diapause and demographic strategy in *Lepidocyrtus lignorum* Fabricius (Collembola; Entomobryidae). Oecologia 58(2):194–199, doi:10.1007/BF00399216

Lenth RV (2016) Least-squares means: The R package lsmeans. J Stat Softw 69(1):1–33, doi:doi:10.18637/jss.v069.i01

Lindberg N, Bengtsson J (2005) Population responses of oribatid mites and collembolans after drought. Appl Soil Ecol 28(2):163–174, doi:10.1016/j.apsoil.2004.07.003

Löpmeier F (1994) The calculation of soil moisture and evapotranspiration with agrometeorological models (in German). Z Bewaesserungswirtschaft 29(2):157–167

MacFadyen A (1961) Improved funnel-type extractors for soil arthropods. J Anim Ecol 30(1):171–184, doi:10.2307/2120

Mäder P, Berner A (2012) Development of reduced tillage systems in organic farming in Europe. Renew Agric Food Syst 27(S1):7–11; doi:10.1017/S1742170511000470

Maltais-Landry G (2015) Legumes have a greater effect on rhizosphere properties (pH, organic acids and enzyme activity) but a smaller impact on soil P compared to other cover crops. Plant Soil 394:139–154, doi:10.1007/s11104-015-2518-1

Martins da Silva P, Carvalho F, Dirilgen T, Stone D, Creamer R, Bolger T, Sousa JP (2016) Traits of collembolan life-form indicate land use types and soil properties across an European transect. Appl Soil Ecol 97:69–77, doi:10.1016/j.apsoil.2015.07.018

Miyazawa K, Tsuji H, Yamagata M, Nakano H, Nakamoto T (2002) The effects of cropping systems and fallow managements on microarthropod populations. Plant Prod Sci 5(3):257–265; doi:10.1626/pps.5.257

Moos JH, Schrader S, Paulsen HM, Rahmann G (2016) Occasional reduced tillage in organic farming can promote earthworm performance and resource efficiency. Appl Soil Ecol 103:22–30, doi:10.1016/j.apsoil.2016.01.017

Ohm M, Schüler M, Fystro G, Paulsen HM (2015) Redistribution of soil phosphorus from grassland to cropland in an organic dairy farm. Landbauforsch Appl Agric Forestry Res 65(3/4):193–203; doi:10.3220/LBF1452867403000

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Henry M, Stevens H et al. (2015) Vegan: Community Ecology Package. R package version 2.3-0

Orgiazzi A, Panagos P, Yigini Y, Dunbar MB, Gardi C, Montanarella L, Ballabio C (2016) A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity. Sci Total Environ 545–546:11–20, doi:10.1016/j.scitotenv.2015.12.092

Peigné J, Ball BC, Roger-Estrade J, David C (2007) Is conservation tillage suitable for organic farming? A review. Soil Use Manag 23(2):129–144, doi:10.1111/j.1475-2743.2006.00082.x

Petersen H (2002) Effects of non-inverting deep tillage vs. conventional ploughing on collembolan populations in an organic wheat field. Eur J Soil Biol 38(2):177–180, doi:10.1016/S1164-5563(02)01145-7

Platen R, Glemnitz M (2016) Does digestate from biogas production benefit to the numbers of springtails (Insecta: Collembola) and mites (Arachnida: Acari)? Ind Crop Prod 85:74–83, doi:10.1016/j.indcrop.2016.02.041

Pommeresche R, Løes AK, Torp T (2017) Effects of animal manure application on springtails (*Collembola*) in perennial ley. Appl. Soil Ecol. 110:137–145, doi:10.1016/j.apsoil.2016.10.004

Ponge JF (1993) Biocenoses of Collembola in atlantic temperate grass-woodland ecosystems [online]. Pedobiologia 37(4):223–244

Ponge JF (2000) Vertical distribution of Collembola (Hexapoda) and their food resources in organic horizons of beech forests. Biol Fertil Soils 32(6):508–522, doi:10.1007/s003740000285

Potapov M (ed) (2001) Isotomidae. Görlitz: Staatliches Museum für Naturkunde Görlitz, 607 p, Synopses on Palaearctic Collembola 3

Querner P (2004) Epigäische Springschwänze (Collembola) von Trockenrasenstandorten in Wien, Niederösterreich und Burgenland [Epigeic springtails (Collembola) of dry grassland sites in Vienna, Lower Austria and Burgenland]. Beitr Entomofaunist 5:17–26

Querner P (2008) Collembola in landscape ecology. 83 p, Vienna: Universität für Bodenkultur (BOKU), PhD Thesis

R Development Core Team (2016) R: a language and environment for statistical computing [online]. Vienna: R Foundation for Statistical Computing. Retrieved from <https://www.r-project.org/> [at 23 Dec 2020]

Sabais ACW, Scheu S, Eisenhauer N (2011) Plant species richness drives the density and diversity of Collembola in temperate grassland. Acta Oecologica 37(3):195–202, doi:10.1016/j.actao.2011.02.002

Sabatini MA, Rebecchi L, Cappi C, Bertolani R, Fratello B (1997) Long-term effects of three different continuous tillage practices on Collembola populations. Pedobiologia 41:185–193

Salamon J-A, Schaefer M, Alphei J, Schmid B, Scheu S (2004) Effects of plant diversity on Collembola in an experimental grassland ecosystem. Oikos 106(1):51–60, doi:10.1111/j.0030-1299.2004.12905.x

Salamon JA, Wissuwa J, Moder K, Frank T (2011) Effects of *Medicago sativa*, *Taraxacum officinale* and *Bromus sterilis* on the density and diversity of Collembola in grassy arable fallows of different ages. Pedobiologia 54(2): 63–70, doi:10.1016/j.pedobi.2010.08.007

Salmon S, Ponge JF, Gachet S, Deharveng L, Lefebvre N, Delabrosse F (2014) Linking species, traits and habitat characteristics of Collembola at European scale. Soil Biol Biochem 75:73–85), doi:10.1016/j.soilbio.2014.04.002

Schachtschabel P (1954) Das pflanzenverfügbare Magnesium des Boden und seine Bestimmung. Z Pflanzenernaehr Dueng Bodenkd 67(1):9–23, doi:10.1002/jpln.19540670103

Schüller H (1969) Die CAL-Methode, eine neue Methode zur Bestimmung des pflanzenverfügbaren Phosphates in Böden. J Plant Nutr Soil Sci 123(1):48–63, doi:10.1002/jpln.19691230106

Skaug H, Fournier D, Bolker B, Magnusson A, Nielsen A (2015) Generalized linear mixed models using 'AD Model Builder'. R package version 0.8.1

Sterzynska M, Kuznetsova NA (1995) The faunal complex of Collembola in lowland subcontinental pine forests (Peucedano-Pinetum) of Poland,

Byelorusia, Lithuania and Russia. Fragm Faun 38(4):145–153, doi:10.3161/00159301FF1995.38.4.145
Sticht C, Schrader S, Giesemann A, Weigel HJ (2008) Atmospheric $CO_2$ enrichment induces life strategy- and species-specific responses of collembolans in the rhizosphere of sugar beet and winter wheat. Soil Biol Biochem 40(6):1432–1445, doi:10.1016/j.soilbio.2007.12.022
Stierhof T (2003) Collembolengemeinschaften in baden-württembergischen Waldböden. Ergänzungsband zur Dissertation. Gießen: Institut für Allgemeine und Spezielle Zoologie, Bereich Tierökologie. Justus-Liebig-Universität Gießen, 375 p
Thibaud JM, Schulz HJ, Da Gama Assalino MM (2004) Hypogastruridae. Görlitz: Staatliches Museum für Naturkunde Görlitz, 607 p, Synopses on Palaearctic Collembola 4
Tomlinson I (2013) Doubling food production to feed the 9 billion: A critical perspective on a key discourse of food security in the UK. J Rural Stud 29: 81–90, doi:10.1016/j.jrurstud.2011.09.001
van Capelle C, Schrader S, Brunotte J (2012) Tillage-induced changes in the functional diversity of soil biota: A review with a focus on German data. Eur J Soil Biol 50:165–181, doi:10.1016/j.ejsobi.2012.02.005
van den Boogaart KG, Tolosana R, Bren M (2014) Compositions: Compositional Data Analysis. R package version 1.40-1. Vienna: Stat Comput
Vandewalle M, Bello F, Berg MP, Bolger T, Dolédec S, Dubs F, Feld CK, Harrington R, Harrison PA, Lavorel S, et al. (2010) Functional traits as indicators of biodiversity response to land use changes across ecosystems and organisms. Biodivers Conserv 19(10):2921–2947, doi:10.1007/s10531-010-9798-9

RESEARCH ARTICLE

# Assessing agro-ecological practices using a combination of three sustainability assessment tools

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Received: May 04, 2020
Revised: August 24, 2020
Revised: October 14, 2020
Accepted: October 15, 2020

HIGHLIGHTS

- **The performance of 131 farms in 15 farming systems were assessed by applying three sustainability assessment tools, namely SMART Farm Tool, Cool Farm Tool, and COMPAS.**
- **Agro-ecological farms generally perform better than conventional farms with regard to biodiversity and water quality.**
- **Biodiversity performance can be improved overall by integrating nature conservation efforts and targeted promotion of species on farms.**
- **While some agro-ecological practices lead to reduced greenhouse gas emissions, in certain contexts, some practices can increase the energy use of the farms.**
- **No clear patterns of the economic performance between conventional and agro-ecological farms are visible.**

KEYWORDS **agro-ecology, agro-ecological farming practices, sustainability assessment tools, SMART Farm Tool (RRID:SCR_018197), Cool Farm Tool**

## Abstract

The alignment of the environmental, economic and social sustainability of farms is necessary for enhancing the provision of public goods in farming. This study combines the use of three tools for the assessment of farm sustainability. It provides first insights into the sustainability performance of farms at different stages of agro-ecological transitions in 15 case studies covering a range of different farming systems across Europe. Each case study reflects a different transition

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towards agro-ecological farming. The tools applied were COMPAS (an economic farm assessment tool); Cool Farm Tool (a greenhouse gas inventory, water footprint and biodiversity assessment tool); and the SMART Farm Tool (a multidimensional sustainability assessment tool).

First results of the use of combined sustainability assessments deepen the understanding of different farming systems. Sustainability performance varies greatly between farms, but overall, agro-ecological farms tend to enhance biodiversity and water quality. For soil quality, no clear patterns could be identified. The same applies to economic performance at different stages of the agro-ecological transition. Quality of life was generally rated medium to high on all investigated farms. The combined sustainability assessment enabled the identification of areas for further policy development.

Aligning the tools required harmonising definitions, simplification and assumptions with regard to the input data of the tools.

## 1 Introduction

The sustainability of farming needs to be enhanced to enable a sustainable food supply for a growing global population while remaining within the planetary boundaries (Campbell et al., 2017; Willett et al., 2019; EEA/FOEN, 2020; Pe'er et al., 2020). Given that the co-provision of public and private goods frequently remains imbalanced and not sustainable at a farm or farm systems level, agro-ecological practices are gaining increasing attention from practitioners and policy-makers (Duru et al., 2015; IPES-Food, 2016; Wezel and Bellon, 2018; HLPE, 2019). Such agro-ecological practices aim at supporting sustainable food production "while being based on various ecological processes and ecosystem services" (Wezel et al., 2014), for example, by substituting synthetically produced inputs with biological alternatives or restoring healthy agro-ecosystems.

The agro-ecological transition of farming systems implies adopting agro-ecological practices. It is linked to the ecosystem services these practices can provide (Altieri et al., 2017; Prazan and Aalders, 2019). There is a wide set of agro-ecological practices with varying degrees of application. A common way to classify them is according to the efficiency, substitution and redesign (ESR) framework, which was first introduced by Hill and MacRae (1996) and which describes different transition stages towards sustainable agriculture (see also Wezel et al., 2014). More specifically, agro-ecological practices may enhance the efficiency of conventional practices (e.g. the precision application of mineral fertilisers), substitute inputs (e.g. applying organic instead of mineral fertiliser), or redesign conventional approaches (e.g. introducing green manure; see Prazan and Aalders, 2019).

However, transitions towards diversified agro-ecological systems remain slow. To some extent, this can be attributed to the challenge of tackling the key dilemma of securing the economic and social sustainability of farms while providing public goods, such as environmental benefits (see, e.g. Otero et al., 2020). This is despite significant political efforts: 40 % of the European Union's 2014-2020 budget was allocated to the Common Agricultural Policy (CAP) (European Parliament, 2020). Yet, questions have been raised over the effectiveness of the underlying policy instruments aiming at enhancing the environmental state of agriculture (Pe'er et al., 2014, 2017, 2020; European Court of Auditors, 2017; Leventon et al., 2017). Despite recognition of the importance of agro-ecological practices for enhancing farm sustainability, identifying and integrating appropriate solutions is challenging and differs across contexts.

European farm-level data are insufficient for capturing agricultural sustainability (Kelly et al., 2018), however, assessment tools exist which can be used to determine the sustainability performance of farms (e.g. Arulnathan et al., 2020; Coteur et al., 2020; Janker and Mann, 2020). For such tools, the term sustainability assessment tools (SAT) is used in this paper if they cover at least one dimension of sustainability. The way they are constructed and the aspects of sustainability they investigate differ significantly (Coteur et al., 2020). The selection of a suitable tool is determined by factors that include the purpose of application as well as thematic and geographic scope (see e.g. Arulnathan et al., 2020; Coteur et al., 2020; Schader et al., 2014). A single SAT is unlikely to capture all of the relevant aspects of sustainability (Gasparatos et al., 2008). A more effective approach for assessing complex systems is to combine the use of different tools (de Olde et al., 2017).

This paper has two aims: i) to explore the potential and challenges of applying different SATs in parallel to assess farm sustainability in different farming systems and ii) to provide first insights into the sustainability impacts of agro-ecological practices implemented across Europe.

A set of different SATs were applied alongside each other (hereinafter called 'combined sustainability assessment'). The intended output was an overview of farm sustainability while also providing an in-depth assessment of at least one environmental topic, and of economic aspects.

To gain insights into all sustainability dimensions with an emphasis on the environmental and economic aspects, three state-of-the art tools were selected: SMART Farm Tool (hereinafter referred to as SMART), COMPAS, and Cool Farm Tool (CFT). SMART is a multidimensional sustainability assessment covering a broad range of sustainability topics. COMPAS covers the economic performance of farms. CFT is a greenhouse gas (GHG) inventory, water footprint and biodiversity assessment tool. Used in combination, the semi-quantitative SMART results are complemented with quantitative evidence obtained from applying COMPAS and CFT.

In the research work reported here, the three SATs were applied to 131 farms in 15 farming systems (case studies). Each of the farming systems comprises farm groups at different stages of agro-ecological transition which are represented by the assessed farms.

The selection of case studies and farms as well as the application of the SATs are described in detail. First insights are provided on how different types of farms perform in relation to core sustainability topics: GHG emissions, biodiversity, soil quality, water quality, productivity/farm income and quality of life. The identified patterns and trends are discussed in relation to relevant literature. The paper also reflects on the role of the current study for informing future policy development as well as some methodology matters.

## 2 Material and methods

The three SATs which were applied and the combined sustainability assessment are described below, followed by a description of their use in 15 case studies across Europe.

### 2.1 Description of the three sustainability assessment tools and the combined sustainability assessment

#### 2.1.1 SMART

SMART (Sustainability Monitoring and Assessment RouTine; RRID:SCR_018197) is an instrument for analysing the sustainability of farms. SMART is considered to be among the most comprehensive SATs for undertaking sustainability assessments, delivering on seven of the eight Bellagio Sustainability Assessment and Measuring Principles (see Arulnathan et al., 2020; Pintér et al., 2012). So far the tool that has been used to assess 4,300 farms in 28 countries. It is based upon the globally recognised Sustainability Assessment of Food and Agriculture systems (SAFA) guidelines (FAO, 2013; Schader et al., 2016).

The four sustainability dimensions of SAFA are organised into 21 themes representing essential elements of sustainability and 58 subthemes (*Figure 2*, on the following page). Themes and subthemes are defined by goals and specific objectives, respectively. Each subtheme has SMART indicators which are associated with measurements relevant to achieving goals.

At its core, the SMART tool performs a multi-criteria analysis (MCA) that makes use of expert derived weights to aggregate indicators of subthemes. The subtheme scores range from 0 % (worst) to 100 % (best), and are mapped onto a colour scheme with five underlying categories of goal achievement (*Figure 1*).

#### 2.1.2 COMPAS

COMPAS (Comparative Agriculture System Model) is a comparative, static, process analytical model used for detailed assessments of economic and technological changes at farm level. The model uses either data from the Farm Accountancy Data Network (FADN) or data that were specifically collected in farm surveys. Farm data are complemented by normative data from farm management handbooks, e.g. regarding energy use of individual machinery or in case detailed accounting records cannot be obtained in full. The data are processed to calculate technical and monetary input-output coefficients of individual production processes (i.e. crops or farm animals). Each production process can be examined in greater detail, e.g. comparing different production intensity levels or field plots.

The output comprises the intermediate indicators of Total Output and Total Intermediate Consumption as well as the key indicators Net Value Added, Farm Net Value Added per Agricultural Work Unit, hereinafter referred to as labour productivity, Net Farm Income, and the gross margins of the crop and livestock products. The process of calculations of all output indicators follows the FADN definition (FADN, 2018).

#### 2.1.3 Cool Farm Tool (CFT)

CFT is an online SAT used to estimate the environmental impacts of food production (CFA, 2019a). The tool estimates on-farm GHG emissions from crops and livestock (Hillier et al., 2011). It consists of a generic set of empirical models of Tier 1, Tier 2, and simple Tier 3 approaches to estimate full farm-gate product emissions (see IPCC, 1997, for a definition of Tiers for GHG estimation in national inventories). The biodiversity module, which was released in 2016, is based on the Gaia biodiversity yardstick (CFA, 2019b; CLM, 2019) and covers the assessment domains of farmed products, farming practices, large habitats, small habitats, livestock, crop and variety, soil fauna, beneficial invertebrates, arable flora, wetland and aquatic flora, woodland flora, arable birds, woodland birds, aquatic fauna, grassland flora and grassland birds.

Each section of CFT was designed to enable farmers to adjust the entered data to obtain insights into the potential reductions in emissions that can result from changing farm management practices. Its global applicability has led to 9,000 users in numerous supply chains, covering 118 countries.

#### 2.1.4 Combined sustainability assessment

Each of the three SATs uses slightly different input data and operates with different types of indicators and outputs, which can be aggregated at different levels. *Table 1* provides a summary of how the three SATs assess the core sustainability topics of GHG emissions, biodiversity, soil quality, water quality, productivity/farm income and quality of life.

The focal points of the tools vary with respect to the level of assessment. The approach of CFT is centred on the assessments of single farm enterprises, COMPAS is based on data from farm enterprises and of the whole farm, and SMART is mainly focused on data at the farm level (see *Table 1*). Data were integrated at the farm level to align outputs of the three

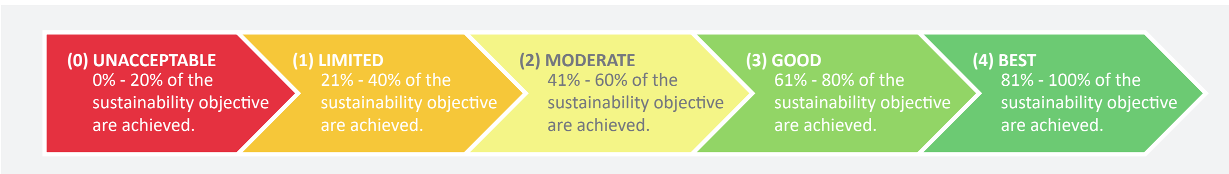


FIGURE 1
The five rating categories of SMART describing the degree of goal achievement in each subtheme

tools in the combined assessments. For CFT, the different emissions from farm enterprises were summed up in a dedicated MS Excel file. For COMPAS, only the farm level indicators were calculated by summing up data from the different farm enterprises.

The ability to represent the local context depends on the level of detail of the SAT. For example instead of selecting a locally occurring crop species (e.g. triticale), a more common crop species (e.g. wheat) had to be selected in one case. With this varying degree of detail between the tools, the input data needed to be aligned.

To streamline the simplifications described above and to align the input data, a Microsoft Excel tool for the data collection for all three tools was developed. This tool supported data entry using automated mechanisms, such as the conversion of data on fresh weight of livestock feed into dry weight (needed for CFT) based on conversion factors from feedipedia.org (Sauvant et al., 2013).

| Theme | Subthemes | | | | |
|---|---|---|---|---|---|
| **GOOD GOVERNANCE** | | | | | |
| CORPORATE ETHICS | Mission Statement | Due Diligence | | | |
| ACCOUNTABILITY | Holistic Audits | Responsibility | Transparency | | |
| PARTICIPATION | Stakeholder Dialogue | Grievance Procedures | Conflict Resolution | | |
| RULE OF LAW | Legitimacy | Remedy, Restoration & Prevention | Civic Responsibility | Resource Appropriation | |
| HOLISTIC MANAGEMENT | Sustainability Management Plan | Full-Cost Accounting | | | |
| **ENVIRONMENTAL INTEGRITY** | | | | | |
| ATMOSPHERE | Greenhouse Gases | Air Quality | | | |
| WATER | Water Withdrawal | Water Quality | | | |
| LAND | Soil Quality | Land Degradation | | | |
| BIODIVERSITY | Ecosystem Diversity | Species Diversity | Genetic Diversity | | |
| MATERIALS & ENERGY | Material Use | Energy Use | Waste Reduction & Disposal | | |
| ANIMAL WELFARE | Animal Health | Freedom from Stress | | | |
| **ECONOMIC RESILIENCE** | | | | | |
| INVESTMENT | Internal Investment | Community Investment | Long-Ranging Investment | Profitability | |
| VULNERABILITY | Stability of Production | Stability of Supply | Stability of Market | Liquidity | Risk Management |
| PRODUCT QUALITY & INFORMATION | Food Safety | Food Quality | Product Information | | |
| LOCAL ECONOMY | Value Creation | Local Procurement | | | |
| **SOCIAL WELL-BEING** | | | | | |
| DECENT LIVELIHOOD | Quality of Life | Capacity Development | Fair Access to Means of Production | | |
| FAIR TRADING PRACTICES | Responsible Buyers | Rights of Suppliers | | | |
| LABOUR RIGHTS | Employment Relations | Forced Labour | Child Labour | Freedom of Association & Right to Bargaining | |
| EQUITY | Non Discrimination | Gender Equality | Support to Vulnerable People | | |
| HUMAN SAFETY & HEALTH | Workplace Safety and Health Provisions | Public Health | | | |
| CULTURAL DIVERSITY | Indigenous Knowledge | Food Sovereignty | | | |

FIGURE 2
Dimensions, themes and subthemes of the Sustainability Assessment of Food and Agriculture systems (SAFA) guidelines. Source: adopted from FAO (2013)

**TABLE 1**

Comparison of tools in the project's focus topics. The "+" sign indicates that the number of indicators scale with the number of crops and livestock on the farm. For a complete list of indicators, see supplementary materials S1.

| | | Level | | Indicator type (Bockstaller et al., 2015) | | | Assessment type | |
|---|---|---|---|---|---|---|---|---|
| Topic | SAT | Crop/live-stock | Farm | Causal indicators | Predictive effect indicators | Measured effect indicators | Semi-quantitative | Quantitative |
| Greenhouse gas emissions | SMART | | X | 74 | | | X | |
| | CFT | X | | | 5+ | | | X |
| Biodiversity | SMART | | X | 72 | | | X | |
| | CFT | | X | 27 | | | X | |
| Soil quality | SMART | | X | 70 | | | X | |
| | CFT | X | X | Topic not covered as a separate assessment, but the soil type (e.g. including parameters such as humidity) serves as an input data domain for GHG emission calculation. Soil fauna is one indicator of the CFT biodiversity assessment. | | | | |
| Water quality | SMART | | X | 61 | | | X | |
| | CFT | | X | Topic not covered as a separate assessment, but land use and management (riverine vegetation, ponds etc.) were entered for biodiversity assessment. | | | | |
| Productivity and farm incomes | SMART | | X | 48 | | 2 | X | |
| | COMPAS | X | X | | 7+ | | | X |
| Quality of life | SMART | | X | 46 | | | X | |
| | COMPAS | X | X | Farm income, which contributes to quality of life, is covered (see above). | | | | |

## 2.2 Case studies

The combined sustainability assessment was first applied in case studies in 15 European countries. This section describes how they were selected and how farms were sampled within each case study.

### 2.2.1 Case study selection

The study aimed to include a broad coverage of farming systems in Europe that are at different stages of agro-ecological transitions. In a first step, the local case study teams developed three proposals for case studies in their country. Prazan and Aalders (2019) document the initial selections which were based upon 19 characteristics such as the production type of farms, sustainability issue, agro-ecological practices, coverage of the value chain by farmers, network presence, level of cooperation, and the presence of innovative policy tools and/or market incentives. These proposed case studies were evaluated based on a reduced set of criteria: i) the presence of innovative policy or market incentives, ii) a high degree of cooperation amongst farmers (and other actors), and iii) the involvement of farms in processing and sales. The final set of selected case studies had to fulfil at least one of these criteria and was recommended to the local case study teams to decide upon together with the local stakeholders involved.

In the final step, representatives from EU-wide institutions validated the final selection of case studies presented in *Table 2*. The set of case studies represents a wide range of production activities and of climatic and ecological contexts of Europe. For each case study, the core dilemma to be addressed by agro-ecological transition was identified by the local research teams.

### 2.2.2 Selection of farms along the agro-ecological transition pathway

The farm sampling strategy aimed to select representative farms with different strategies and performance profiles along the agro-ecological transition pathway following the previously introduced ESR framework (*Figure 3*). Based on this framework and the farm typology developed by Prazan and Aalders (2019), a guideline provided instructions to local case study teams on how to select farms. The first dimension of the farm typology (farm production system according to FADN) served to focus the case study on a certain farm production system (dairy, mixed, perennial farms etc.) to ensure the comparability between the farms in one case study. The second dimension (agro-ecological practices) helped define case study-specific farm groups along the transition pathway for the farm quota sampling. The third dimension (socio-ecological system context) was used to further characterise these groups.

A total of 51 farm groups were examined in the 15 case studies. These groups are presented in *Table 3* according to their stage of transition. For example, in the Swiss case study, four farm groups are described: one group of conventional farms specialised in pig and dairy representing the current system in the case study area (Stage 0). The second group consists of organic farms specialised in pig and dairy representing the input substitution stage (Stage 1 in the Swiss case study). Two additional farm groups (organic farms with

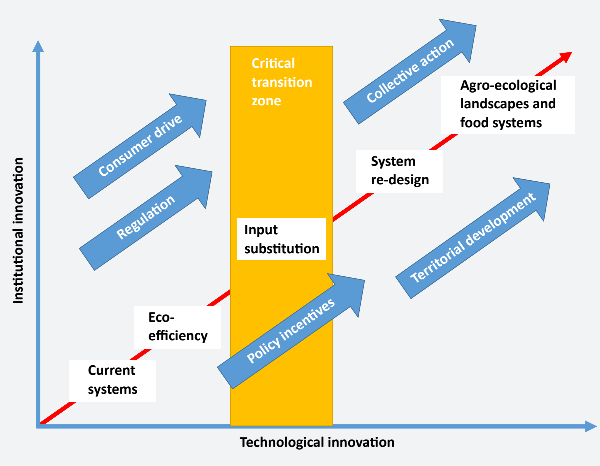


**FIGURE 3**
Representation of a transition pathway with different stages of transition. Source: Tittonell (2014), adapted by Prazan und Aalders (2019)

mixed special crops and extensive mixed livestock farms) represent the stage of system redesign, which equals Stage 2 in the Swiss case study.

Approximately 2.5 farms per farm group were then selected on average for the assessments (131 farms in total). The specific farms were chosen based on input from local stakeholders, such as farmer associations, local authorities, or rural advisory services. They provided the insights required for selecting farms representing the defined farm groups and established the contacts with the farmers. Half of the farm groups defined along the transition pathway (1st stage and 2nd stage in *Table 3*) are certified as organic. Although agro-ecology is not defined by a standard or a certification, organic farming can be still seen as a laboratory for ecological innovation (Tittonell, 2014) and, consequently, overlaps significantly with agro-ecological practices (Migliorini and Wezel, 2017).

**TABLE 2**
Overview of case studies and their dilemmas, which frame the development of practice-validated strategies for agro-ecological transitions. For each case study, the geographical scope is provided by referring to the level of the Nomenclature of Territorial Units for Statistics (NUTS).

| Country | Case study dilemma | Geographical scope (NUTS level) |
|---|---|---|
| Austria (AT) | Increasing carbon sequestration in soils and soil quality without losing economic viability of arable farms | NUTS 3 |
| Czech Republic (CZ) | Reducing soil degradation without losing economic viability of arable farming | NUTS 3 |
| Germany (DE) | Reducing pressure on ecosystem (water, soil, biodiversity) without losing economic viability | NUTS 3 |
| Finland (FI) | Reducing environmental impact of dairy farming without losing economic viability | NUTS 3 |
| France (FR) | Reducing dependency of external fertilisers and pesticides without losing economic viability | NUTS 1 |
| Greece (GR) | Reducing use of agro-chemicals in fruit production without losing economic viability | NUTS 3 |
| Hungary (HU) | Improving soil quality without losing economic viability | NUTS 0 |
| Italy (IT) | Increasing diversification without reducing profitability | NUTS 2 |
| Lithuania (LT) | Enhancing economic viability and competitiveness of dairy without intensifying production | NUTS 1 |
| Latvia (LV) | Enhancing economic viability and competitiveness of dairy without increasing pressure on water and biodiversity | NUTS 2 |
| Romania (RO) | Enhancing economic viability and competitiveness of small-scale farming without damaging cultural landscape and biodiversity | NUTS 1 |
| Spain (ES) | Improving economic resilience without increasing pressure on the ecosystem | NUTS 1 |
| Sweden (SE) | Diversifying specialised ruminant livestock farms to include more crops for direct human consumption without losing economic viability | NUTS 0 |
| Switzerland (CH) | Reducing water eutrophication and ammonia emission from intensive livestock keeping without losing economic viability | NUTS 1 |
| United Kingdom (UK) | Producing public goods while maintaining viable production of private goods, and securing economic and social sustainability at a farm level | NUTS 2 |

**TABLE 3**
Overview of the farm groups in the case studies and their classification along the transition pathway.
Stage 0 comprises farms which are not agro-ecological. The term 'in transition' used in the table refers to farms in transition to input substitution by applying some practices used in organic farming. 'Org.' stands for organic farming, 'Conv.' for conventional farming.

| | | Stage on the agro-ecological transition pathway | | |
|---|---|---|---|---|
| | Main agro-ecological practices | Stage 0 (S0) | 1st stage | 2nd stage |
| AT | Soil management (humus formation) | Conv. fruit farms | S0 + participating in humus project | Org. fruit farms participating in humus project |
| | | Conv. mixed livestock (pig) arable farms | S0 + participating in humus project | Diversified mixed livestock (pig, poultry, cattle) arable farms, participating in humus project |
| CZ | Livestock density/ soil management | Conv. specialised dairy | Org. specialised dairy | |
| FI | Livestock density/livestock diversity | Conv. specialised dairy | Org. dairy farms (incl. some more diversified) | |
| | | | S0 + biogas project | |
| FR | Weed, pest and disease control | Conv. perennial (wine) | Partially org. perennial (wine)/ in conversion | Demeter perennial (wine) |
| DE | Fertiliser and soil management, flower/buffer strips, crop diversification | Specialised arable farms (with minor pig systems) | S0 + some agro-ecological practices | |
| GR | Integrated crop management (ICM, fertiliser and soil), pest control (mating disruption) | Fruit farms without ICM or mating disruption technique | Fruit farms with ICM or mating disruption technique | Fruit farms with ICM and mating disruption technique |
| HU | Soil management (erosion) | Arable farms | S0 + reduced tillage | No-till arable farms |
| IT | Fertiliser management/soil management | Intense perennial (wine) | Org. perennial (wine) | Org. perennial (wine) with advanced soil management |
| LV | Livestock diversity | Conv. specialised dairy | S0 + grazing | Org. specialised farms |
| LT | Livestock diversity | | Extensive specialised dairy farms | Extensive mixed dairy |
| | | | Org. specialised dairy | |
| RO | Livestock density/fertiliser management/weed, pest and disease control | Conv. specialised dairy | Org. specialised dairy | |
| | | Conv. cattle rearing and fattening | Cattle rearing and fattening in transition | |
| | | | Mixed fruit/arable farms in transition | Org. mixed fruit/arable farms |
| ES | Crop spatial diversity | Conventional arable farms | Arable farms in transition | Org. arable farms |
| SE | Livestock diversity/density | Conv. specialised beef farms | Org. and/or more diversified dairy farms | Org. diversified production of beef or lamb and crops |
| | | | Org. and/or diversified beef or lamb farms | |
| CH | Livestock diversity/density | Conv. specialised livestock farms (pigs, dairy) | Org. specialised livestock farms (pigs and dairy) | Org. mixed special crop–livestock farms |
| | | | | Org. extensive mixed livestock farms |
| UK | Fertiliser and soil management and pest control | Conv. arable farms | Mixed farms in transition | Org. arable farms |
| | | Conv. mixed farms | | Org. mixed farms |

### 2.2.3 Data collection and evaluation

The data collection and evaluation was mainly done by the local case study teams with support of a SAT coordinator for each of the three tools (see *Figure 4*).

To create a common understanding of the assessment process among the case study teams and to streamline farm assessments, a guideline was provided to set out the steps needed for the farm assessment, such as reducing the assessment time by omitting farm enterprises of limited relevance in the operation of CFT and COMPAS. The guideline was accompanied by seven webinars and a six-day, face-to-face field training course.

The farm visits listed in *Figure 4* each lasted between three and four hours. Throughout the whole process, the local case study teams verified data with the SAT coordinators by i) drawing attention to any uncertainties about data quality in a dedicated online forum and ii) incorporating the feedback from the spot check of their data conducted by the three SAT coordinators. A separate guideline was provided for the data quality review process and result evaluation.

In a next step, the results were analysed by the local case study teams by comparing the results of the farm groups along the transition pathway with similarities and differences relating to the core sustainability topics. This approach to result evaluation aimed at i) accounting for the local context of each case study and ii) focusing the analysis of the more than 10,000 data records. To enable consideration of context, causalities, and potential data issues, a section of the guidelines framed the comparison between farm groups with the following questions (summarised):

- How do farm groups compare to structural farm data available for the region (e.g. FADN data)?
- What are the causalities or contributions of different processes in the SATs behind the observed patterns?
- How does the sample size affect the comparison?
- How does the farm type affect the comparison?
- What are other potential limitations for drawing conclusions?

The guideline also provided a structure for reporting the results (see supplementary materials S2).

In the final step, all case study reports were iteratively summarised for each core sustainability topic (see Section 2.1.4) accounting for patterns of similarities and differences between the farm groups.

The aggregated findings in pesticide use, fertiliser use, soil management, quality of life, and income volatility were complemented with a central data analysis in SQL Server Management Studio to query SMART indicator data across several case studies and MS Excel to further evaluate the query results (e.g. comparing conventional and agro-ecological farms).

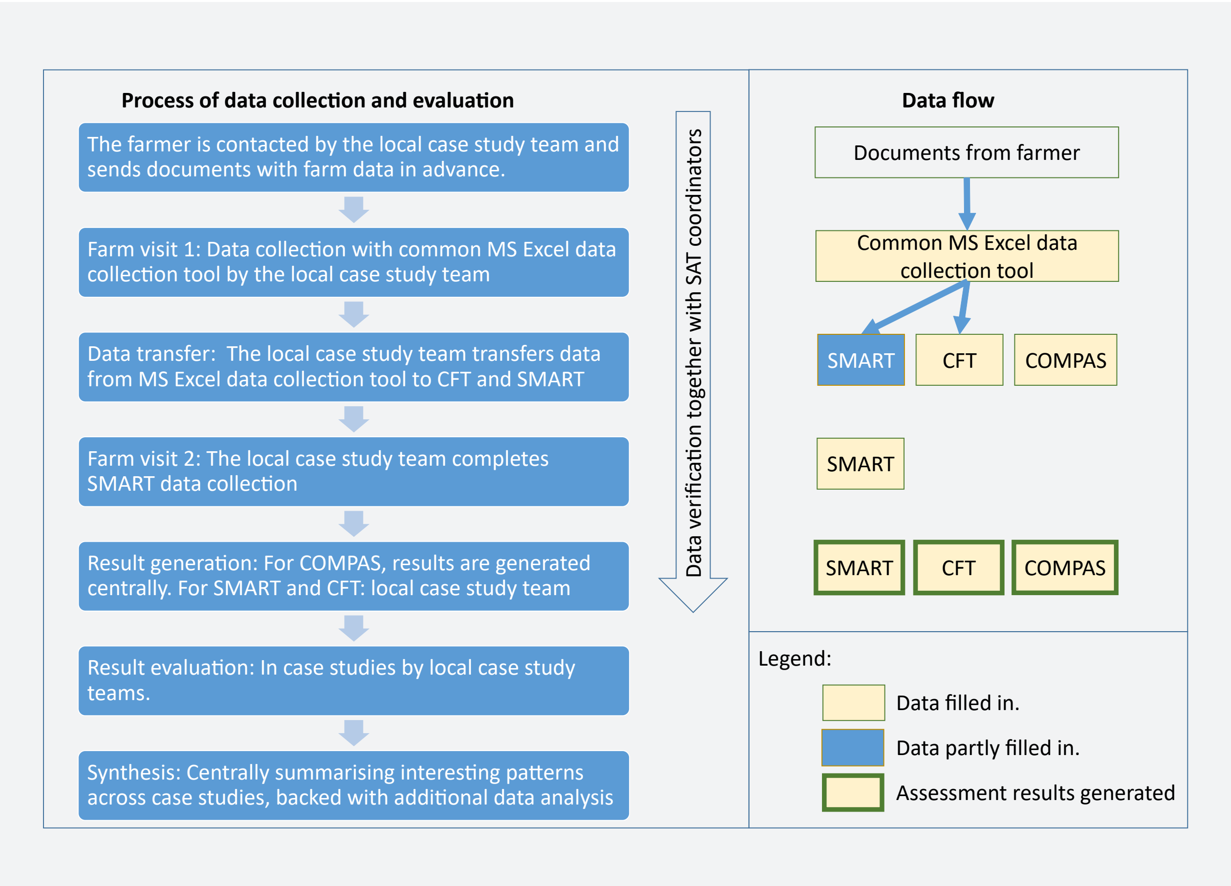


FIGURE 4
Data collection and evaluation workflow

## 3 Results and discussion

The patterns and trends identified from the application of the SATs in the case studies are summarised in *Table 4*. The results are based on the analysis of similarities and differences between the defined agro-ecological farms (i.e. farms in the 1st and 2nd stage of agro-ecological transition, n=84) and their conventional counterparts in the case studies (n=47, *Table 3*). These comparisons were conducted within the context of each case study and, in selected areas, explored in all or several case studies (see section 2.2.3). The observations are summarised in the following sections.

The farm groups are a simplification of the wide range of agro-ecological transition perspectives in the case studies. The implications of this heterogeneity are discussed in Section 4.2. The first results are accompanied by the code of the countries representing those case study reports in which the corresponding findings were explicitly mentioned. The underlying data is provided in the database compiled by Landert et al. (2019).

The results described below refer to SAT performance ratings, illustrated in *Figure 5* by SMART results. For example, a higher rating for the SMART subtheme Soil Quality implies a better performance of farms in aspects related to soil quality (see section 2.1).

### 3.1.1 Greenhouse gas emissions

In the case studies, the production systems largely determined the GHG emissions of farms and the potential for mitigation. The level of agro-ecological transition appears to generally have less impact. Nevertheless, for the perennial systems of France and Greece, the results of CFT suggest that agro-ecological practices can lead (in some cases) to an increase in GHG emissions. Reasons for such increased emissions are, e.g. the increased fuel use for mechanical weeding (FR) and drip-irrigation in the case of some Greek conventional and agro-ecological peach farms, which leads to increased energy use compared to the flood irrigation of the other farms in the sample.

In arable farming, the SAT assessments identified the use of nitrogen (N) fertiliser as the main contributor to emissions because of nitrous oxide (N2O) and emission from the production of synthetic fertilisers. This is reflected in the CFT results for the Swiss case study, in which the contribution of N-fertiliser application to crop and grassland-related GHG emissions was 36 % (on average) across all farm groups. Some of the agro-ecological farm groups investigated used less N-fertiliser, which was reflected in lower GHG footprints per hectare in CFT and a higher SMART score, compared to the more conventional counterparts: In Spain, on average the agro-ecological farms used 107 kg N $ha^{-1}$ of agricultural area (180 kg N $ha^{-1}$in case of conventional farms), while in Switzerland these farm groups used an average of 89 kg N $ha^{-1}$ (169 kg N $ha^{-1}$ in case of conventional farms). The CFT assessment shows that soil conservation techniques in arable systems contribute (temporarily) to GHG mitigation (AT, CH, IT, HU). Yet, the difference in the average share of agricultural land under reduced tillage between agro-ecological and conventional farm groups was small across the four case studies: 62 % in case of agro-ecological farms versus 58 % in case of conventional farms. Despite the similar share of reduced tillage, the weed control differed: the conventional group did not use undersown cover crops at all, compared to an average share of 6 % area with undersown cover crops on the agro-ecological arable land. Also, the average share of arable area where catch crops are grown was only 5 % on conventional farms compared to 12 % in the case of agro-ecological farms. The SAT results also reveal lower pesticide use on the agro-ecological farms (LV, ES), which reduces GHG emissions to a small extent on agro-ecological farms.

**TABLE 4**
Summary of identified patterns and trends

| Sustainability topic | Identified patterns and trends |
|---|---|
| Greenhouse gas (GHG) emissions | Different agro-ecological field management practices have a reducing effect on the total GHG emissions of farms. Some agro-ecological practices increase total farm emissions. |
| Biodiversity | Biodiversity scores are mainly determined by farming practices. Agro-ecological farm groups tend to show higher levels of biodiversity than their conventional counterpart. However, agro-ecological farming practices are not necessarily associated with measures designed to promote biodiversity. |
| Soil quality | Farm type (conventional or agro-ecological) did not have a consistent effect on SAT scores for soil quality. As one reason, some practices are applied by all farm types such as determining soil fertiliser requirements which contributes positively to the soil quality scores. |
| Water quality | Agro-ecological farm groups show higher scores for water quality, particularly due to reduced use of pesticides, fertilisers, and practices such as erosion management. |
| Productivity and farm incomes | The majority of farms generate positive income, but subsidies (including direct and other payments) represent a major proportion of the farm income in all countries. As such, SAT results show no clear patterns between labour productivity, farm income and the stage of agro-ecological transition. |
| Quality of life | The quality of life is generally high on all farms, whether they are oriented towards agro-ecological practices or not. A lower degree of mechanisation (and therefore higher physical workload) impacts quality of life negatively in some case studies. |

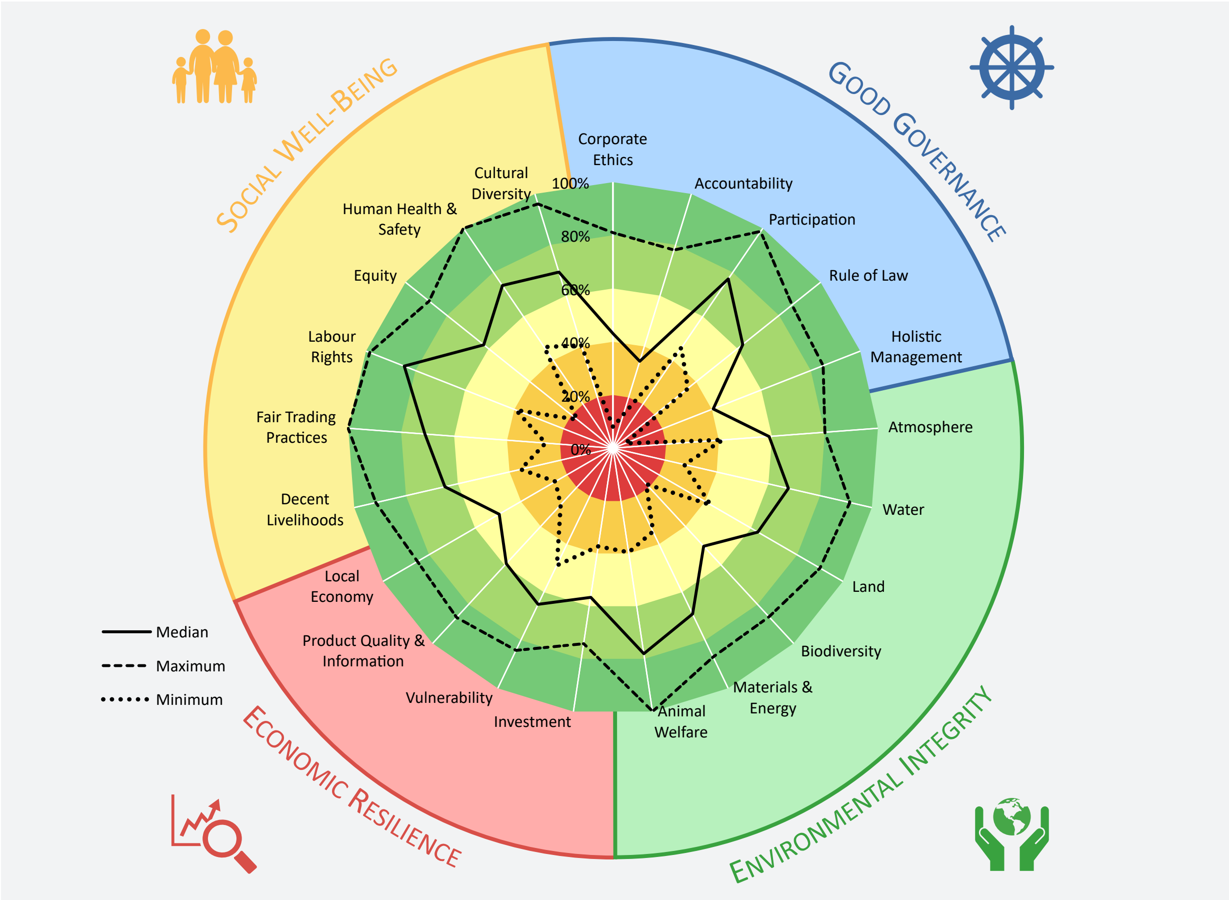


**FIGURE 5**
Ratings for the 21 SMART themes across all case studies

### 3.1.2 Biodiversity

SATs cover different aspects of biodiversity, including genetic, species, and ecosystem diversity (SMART, see Section 2.1.1) or, in the case of CFT, scores that express the impact of farming on certain biotic communities, such as soil fauna (see Section 2.1.3). *Figure 6* shows the scores for soil fauna across the farm groups in the case studies.

With regard to biodiversity, CFT and SMART rank agro-ecological farm groups higher than their conventional counterparts in most cases. Across all case studies, agro-ecological farms have an average rating of 54 % in SMART, whereas conventional farms score 42 %. The SATs yield higher biodiversity scores because of differences in farming practices, such as soil conservation practices (HU), biodiversity conservation (DE), a higher diversity of livestock, and crop rotation elements (CH, ES, IT, LV, RO). In the latter case, agro-ecological farms across all case studies exhibit, on average, a minimum number of 3.71 crops in the rotation compared to 3.48 on conventional farms. In addition to crop diversity, also the cultivation on small plots (RO), the application of less N-fertiliser (CZ, CH, ES, RO, UK) and less pesticides (CH, CZ, ES, GR, RO, SE, UK; number of active ingredients) lead to higher biodiversity scores on agro-ecological farms. The use of less pesticides in the cited cases is also reflected across all

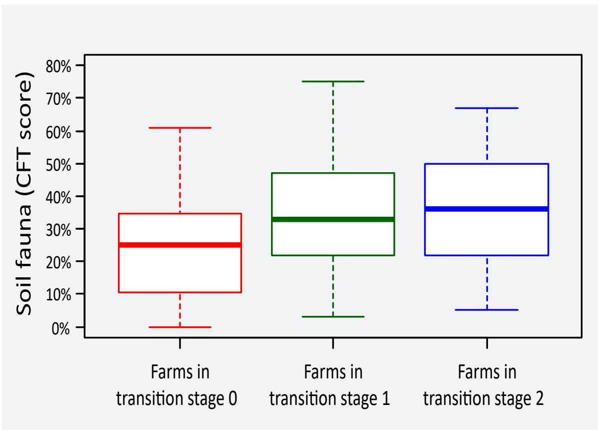


**FIGURE 6**
Median soil fauna biodiversity score provided by CFT (0 – 100 %) including quartiles, minimum and maximum for farms in the case studies (excluding Finland and Spain where no CFT biodiversity data is available) at the three agro-ecological transition stages (see Table 3)

case studies by a lower average number of active ingredients being used on agro-ecological farms compared to conventional farms. Correspondingly, agro-ecological farms (including 40 farms with no pesticides registered) scored better in the SMART indicators with regard to the toxicity attributes of pesticides, such as acute (inhalation) toxicity, chronic toxicity, and toxicity to bees and aquatic organisms. The active ingredients registered on agro-ecological farms are, on average, less persistent in water (248 days versus 282 days of half-life time in the case of conventional farms). However, the greater use of copper on agro-ecological farms led to a high average persistence of pesticides in soils (243 days [104 days without considering copper] of half-life time versus 237 days for pesticides used on conventional farms).

It appears that agro-ecological farming practices do not necessarily correlate with targeted measures to promote biodiversity or the creation of large habitats (AT, CZ, LT, LV): The median CFT score for large habitats equals 2 % for agro-ecological farms (on a scale from 0 % to 100 %). Results from SMART show that the share of agro-ecological farms which undertake targeted promotion (of one group) of species (23 %) is even lower than for conventional farms (33 %).

### 3.1.3 Soil quality

While the CFT scores for soil fauna (an indicator of the biodiversity assessment) suggest that agro-ecological farms perform better (*Figure 6*), the SMART results did not show clear patterns between the groups of conventional and agro-ecological farms. The assessments of soil quality and soil fauna by the two SATs are mainly based on farming practices and land use, with additional topics, such as soil pollution and erosion, assessed by SMART (see supplementary materials S1).

While indicators in these different topics all similarly contribute to the final SMART soil quality score, it was in some case studies positively influenced by the following agro-ecological practices: mulching (AT, FR), higher use (twice the level) of legumes in crop rotation in the agro-ecological group than in the conventional farm group (CZ), maintenance of grass cover between vine rows (FR, IT), undersown crops (CH, CZ), reduced till (AT), no-till (HU), reduced soil contamination due to pesticide use (LV, GR), or determining soil fertiliser requirements (LV). The higher share of legumes can be identified across all case studies (on average, 10 % on conventional arable land versus 17 % on agro-ecological farms). The farm groups also differed with regard to the undersowing of crops (3 % on average on conventional arable land versus 12 % on agro-ecological farms). Although the application of reduced tillage varied less between the farm groups, it is still substantial (36 % on average on conventional agricultural area versus 45 % on agro-ecological farm land). The same applies to the green cover outside the growing period (50 % on average on conventional arable land versus 65 % on agro-ecological farms).

Composting was not explicitly mentioned as playing an important role. Correspondingly, only 14 % of agro-ecological farms which apply organic fertiliser apply plant or livestock-based compost (15 % of conventional farms).

### 3.1.4 Water quality

Most agro-ecological farm groups perform better across the case studies, particularly due to a reduced use of pesticides (AT, CZ, GR, LV), fertilisers (AT, CH, CZ, GR, LV, LT, SE), and improved erosion management (AT, CH). Overall, the median SMART scores for the farm groups in all case studies ranged between 60 % and 80 % (*Figure 7*).

Buffer strips along surface waters, an important measure of the current CAP, cross-compliance, and post-2020 CAP conditionality, contributed to a high SMART rating (CZ, HU).

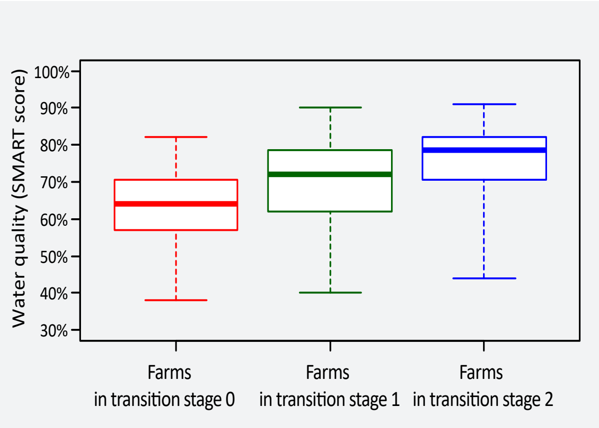


FIGURE 7

Median SMART scores of goal achievement for the sub-theme water quality including quartiles, minimum and maximum, separately displayed by the three agro-ecological transition stages (see Table 3) in all case studies

### 3.1.5 Productivity and farm incomes

The majority of farms (95 %) generate positive net incomes with their crop and livestock farming activities in the reference year. This was true for 77 % of the conventional farms and 92 % of the agro-ecological farms over the last five years. However, subsidies represent a major share of the farm income in all countries. The SAT results show no clear patterns between labour productivity, farm income, and the stage of agro-ecological transition. In one case (AT), results from different SATs yield contradictory results, which reflects COMPAS's focus on economic performance in a particular year, compared to SMART tending to assess medium term economic resilience. In the Swiss case study, agro-ecological farm groups were reported to show lower labour productivity than their conventional counterparts. In other cases, higher subsidies (LV), sales through shorter supply chains (AT, FR, LT), or higher price premiums from organic farms (FR) contribute to the net farm income of agro-ecological farms.

### 3.1.6 Quality of life

With SMART scores ranging from 48 % to 92 % (average: 74 %), quality of life can be considered medium to high on all of the assessed farms. This suggests that agriculture provides viable livelihoods, i.e. modes of living that fulfil people's needs and expectations, although there are exceptions (RO). Reasons for the high scores are the profitability of farms and the generally high labour standards in Europe (CZ, ES, FR, SE), in spite of common characteristics, such as extra hours worked (see also section 4.1).

The results indicate scores of a slightly lower quality of life in some case studies for agro-ecological farms due to less mechanisation, resulting in higher physical workload (CH, ES, LV).

### 3.1.7 Integrated perspective on sustainability issues

The combined sustainability assessment made it possible to identify some initial sustainability synergies and trade-offs in the case studies, for example, in Spain, where farms with a higher biodiversity performance have lower GHG emissions. In the Latvian case study, mineral fertiliser and pesticide applications are the reason for synergies between efforts to increase biodiversity and improve water quality. In place of mineral fertilisers, organic farms in Latvia often use perennial grasslands with nitrogen-fixing legumes to maintain soil fertility. In Greece, the agro-ecological practices used led to synergies between efforts relating to soil and water quality.

Two case studies explicitly reported trade-offs between the economic performance of the farm and biodiversity (CH, CZ). In contrast, the Italian case study showed that more specialised and economically viable winemakers implement more agro-ecological practices. However, a transition to agro-ecological practices may also result in trade-offs in the environmental dimension. In some cases, GHG emissions rise due to higher energy use, caused, for example, by increased mechanical weeding or energy-demanding irrigation (FR, GR). In the Swedish case study, greater plant protein production meant more intensive arable farming, which led to a decrease in performance with regard to soil quality.

## 4 Discussion

### 4.1 Patterns and trends

The combined sustainability assessment showed what agro-ecological practices mainly contributed to the core sustainability topics investigated. These practices led to generally higher scores of agro-ecological farm groups in the case of biodiversity and water quality, compared to their non agro-ecological counterparts. In the other four sustainability topics investigated, the results imply that a variety of factors, which are independent of agro-ecological transition, determine the sustainability performance of farms, e.g. the farm production system. In addition, the results suggest that agro-ecological practices can, in certain contexts, also have negative impacts on certain sustainability topics.

Most examples of such negative impacts are related to greenhouse gas emissions and comprise practices such as mechanical weeding in French organic vineyards. The associated increase in fuel consumption is reported for other organic production systems by Smith et al. (2015). On arable farms, soil conservation techniques were a key factor for reducing greenhouse gas emissions. Sanz-Cobena et al. (2017) confirm this positive impact in their review for the Mediterranean area. Yet, they also point out that the rate of carbon sequestration is likely to decrease over time (Sanz-Cobena et al., 2017). In addition, there are general uncertainties related to the potential of no-till to increase soil carbon stocks (Ogle et al., 2019).

In the case of the Hungarian case study, no-till led to higher CFT soil biodiversity scores. This positive effect in the model is confirmed in field studies (e.g. Adl et al., 2006). The higher number of crops on farmland and the smaller plot size had a positive effect on the biodiversity scores. Sirami et al. (2019) identified plot size to be a key determinant for multitrophic diversity in their study of 435 landscapes across 8 regions of Europe and North America. They found that the effect of crop diversity on the multitrophic diversity varies depending on the extent of areas with semi-natural cover. In the pan-European study of Billeter et al. (2008), the crop diversity on farms had a positive impact on the diversity of three arthropod species groups. The authors also found a negative effect of high nitrogen fertiliser use (>150 kg N $ha^{-1}$ $year^{-1}$) on plant species diversity and on the number of bird species. This provides another reason for the negative biodiversity ratings among the conventional farm groups: farms with a mean input in excess of 170 kg N $ha^{-1}$ $year^{-1}$ score lowest for the corresponding SMART indicator. A reduction in N input in the range below 25 kg N $ha^{-1}$ $year^{-1}$ is not considered by SMART.

The lower use of pesticides in agro-ecological farm groups (lower number of active ingredients employed) and the associated use of less hazardous pesticides also contributed to the higher SAT rating with regard to biodiversity. Again, these findings are identified in field studies as main factors influencing biodiversity, such as the pan-European study by Emmerson et al. (2016). Although the agro-ecological farms investigated perform well with regard to their farming practices, in several case studies they fall short in the provision of larger semi-natural habitats, which is another key aspect of how agriculture impacts biodiversity (Billeter et al., 2008).

Although agro-ecological practices have been identified to contribute to the soil quality in the case studies, no clear pattern was observed with regard to SMART ratings between conventional and agro-ecological farm groups. This somewhat counterintuitive observation can be explained by the fact that such practices are important for the calculation of the soil quality score of SMART, but other factors, such as land use, soil condition, or additional farming practices, have a similar importance in the calculation of the score. Consequently, these factors need to be looked at more closely in further steps of the data analysis in order to identify those practices, which can be improved on both, agro-ecological and conventional farms with regard to soil quality.

A further observation is that composting was not a common practice on agro-ecological farms in the case studies despite its potential to improve soil quality (Martínez-Blanco et al., 2013). This contrasts with the findings of Viaene et al. (2016) in which 87 % of the surveyed organic farmers used compost (in contrast to 14 % of the agro-ecological farms in this study). This large difference in use of composting cannot fully be explained by the variation between countries or regions. The use of compost seems also to vary between farms in the same case study. Generally, this shows that there is an untapped potential for policies and farm advice to promote composting and minimise barriers to its uptake.

Similar to findings for biodiversity, the SAT ratings for water quality were more negatively impacted by the N-application rate on conventional farms than agro-ecological farms. The use of fewer pesticides had positive implications for aquatic organisms. The rating effect of N-application rate is to be taken indicatively since the corresponding indicator does not consider agri-environmental factors such as climatic conditions, soil water content, crop type, soil type, or the use of catch crops, all of which are identified as important determinants for nitrate leaching by Beaudoin et al. (2005).

Although most of the farms were profitable during the reference year, the net farm income of conventional farms was shown to be slightly more volatile over time than that for agro-ecological farms. However, this pattern of income volatility does not seem to be general in nature, since Krause and Machek (2018) were not able to detect such a pattern in their comparison between Czech organic and conventional farms. Meuwissen et al. (2018) identified other factors that are important for income volatility, such as the country and farm production system. While in our study no overall patterns for farm income could be identified, Krause and Machek (2018) note that Czech organic farms tend to have a higher profitability (determined by the return on assets). This last finding is further underpinned by the meta-analysis of Crowder and Reganold (2015) on profitability of organic farms for 55 crops across 14 countries. Moreover, in the case of conventional arable farms in France, Lechenet et al. (2017) did not observe a general loss of profitability when reducing the use of pesticides. Yet, empirical evidence varies across studies, depending on the country and production system (Krause and Machek, 2018). The relevance of short supply chains and higher prices from premia for profitability has been confirmed in other studies (Crowder and Reganold, 2015; Hatt et al., 2016; Krause and Machek, 2018). On Swiss agro-ecological farms, the lower degree of mechanisation, the lack of innovative collaboration models (i.e. group farming), and the absence of short supply chains might all have been contributing reasons for the lower labour productivity.

The general profitability of the investigated farms directly or indirectly contributed to high ratings for some SMART indicators of the quality of life subtheme. In line with that, Besser and Mann (2015) found that farm income (measured by proxies of farm size and perceived financial situation) positively influences (to different extents) the relatively high work satisfaction of farmers in Switzerland and northern Germany (approximately 7 on a scale from 1 to 10). However, the relatively high scores for the SMART quality of life subtheme also stems from the fact that the used indicators rated European labour standards as high (also see section 4.2). In this study we could not identify clear differences between agro-ecological farms and conventional farms; however, there is some evidence for a higher satisfaction among organic farmers compared to conventional farmers in France (Mzoughi, 2014; Bouttes et al., 2020).

Throughout the analysis of the results, some synergies emerged. An example is the higher rationalisation and economic success in the Italian case study that led to the adoption of more agro-ecological practices for managing vineyards. This is similar to findings reported for vineyards in Portugal by van der Ploeg et al. (2019). In general, reducing fertiliser and pesticide inputs (given the limitations of generalizing such reductions, as discussed above) also leads to synergies between different aspects of sustainability (apart from the risk of increasing GHG emission due to higher fuel use related to mechanical weeding). Therefore, unsurprisingly, reducing the use of pesticides and fertilisers is at the core of the EU's Farm to Fork Strategy (European Union, 2020). The results of this study provide additional indications for policy priorities. For example, with respect to biodiversity, the lack of large habitats found in this study suggests a need for improving the embedding of conservation efforts in measures in the CAP post-2020, as recommended by groups such as the Alliance Environment (2019). By revealing a low level of diffusion of certain environmentally beneficial practices (such as composting), the results of this study provide indications on practices that could be incentivised under the new Eco-schemes in EU Member States.

## 4.2 Combined sustainability assessment framework and process

The approach taken in this study enabled the benefit of combining different perspectives on sustainability, as suggested by previous studies, such as Gasparatos et al. (2008). This combination of different perspectives allowed to relate the performance in the core sustainability topics with each other and therefore the identification of patterns of synergies and trade-offs.

With the exception of the underlying SAFA framework in the case of SMART, all SATs represent a top-down approach (Binder et al., 2010) with only partial involvement of stakeholders in their development. This contrasts with the recommendations of Arulnathan et al. (2020) and de Olde et al. (2017) to engage stakeholders in the development of such tools to increase their acceptance by end-users and to take local contexts into account. As a consequence, there is a trade-off between the desired global applicability of the SATs and how local context is accounted for. Coteur et al. (2016), Janker and Mann (2020), Röös et al. (2019), and others stressed the need for taking the local context into account, and Binder et al. (2010) confirmed that there are trade-offs between context applicability and standardisation in tools for benchmarking. This standardisation manifests itself, for example, in the SMART quality of life subtheme, in which some indicators reflect relatively low standards in comparison to those in the more developed European context. For example, fulfilling the International Labour Organisation Fundamental Principles and Rights at Work (ILO, 1998) tends to be embedded in the operation of all farms in European countries, which is reflected in the relatively high scores of the assessment.

As outlined in section 2.1.4, where necessary, the output of the tools was aggregated to the farm level to overcome problems of mismatches in scale. This step proved to be especially challenging when calculating greenhouse gas emissions, which was prone to errors of double accounting, for example, due to the use of common infrastructure for electricity or due to emissions from feed grown on the farm. These issues were underestimated and suggest a need for more emphasis on the methodology for this step in future projects and for the inclusion of specific indications in each tool on how these emissions from single farm enterprises may be aggregated to higher levels.

Apart from the issues arising from the different levels of assessments, the alignment of input data referred to in section 2.1.4 required simplifications and assumptions to address differences in concepts and to align the SATs to an interdisciplinary approach to data collection. The interdisciplinary approach represented a strength of this study since it is being widely accepted as the basis for advancements in sustainability issues, and the employment of assessment approaches is seen as beneficial for ensuring the plurality of views (de Olde et al., 2017). However, the interdisciplinary approach was also very demanding for both interviewers and farmers. This may have aggravated the common challenge of all models relying on empirical survey data, namely the risk of subjectivity (Biemer et al., 2013). Both the matching of a qualitative answer in the interview with one of the pre-defined answers in the questionnaire and the derivation of quantitative data together with the farmer were prone to this risk.

With the complexity associated with case studies in 15 European countries, this study was potentially vulnerable to heterogeneous assessments. Since the primary data evaluation was carried out separately in each case study (see section 2.2.3), the level of subjectivity within each case study should be the same. Nevertheless, comparisons across case study findings should be interpreted with caution since the exploratory approach of comparing the farm groups with regard to similarities and differences in selected topics (see section 2.2.3) yielded different focus points in the reporting by the case studies. Such inconsistencies may also stem from local adaptions of the data collection procedure that were necessary, e.g. how the interviews were conducted. In some case studies, due to long distances between farms, interviews were conducted in one session, which could have led to loss of concentration for the interviewer and the farmer.

Another reason for heterogeneous assessments was the definition of system boundaries: this mainly affected the calculation of the aggregated farm level greenhouse gas emissions for which it was possible, due to the high demand in interview time on diversified crop farms (> 5 elements in crop rotation), to leave out crops with a share of less than 10 % of the arable land. The same was true for diverse livestock farms (> 2 livestock species) with livestock accounting for less than 10 % of the total livestock units on the farm. The left-out livestock was also not considered for the economic analysis in COMPAS. These means of shortening the assessment time were applied to a varying degree across the case studies. This heterogeneity may have been caused because the mentioned cut-off criteria were not directly incorporated into the tools themselves (Arulnathan et al., 2020).

Apart from the limitations relating to combining the tools, the data collection and evaluation, another limitation of this study was that farms were sampled with quota sampling instead of random representative sampling, which was beyond its scope. Consequently, the small number of farms assessed in each case study is unlikely to be sufficient to cover the heterogeneity of farms within the farm groups. This introduced a degree of uncertainty in the comparisons that can be made between the sustainability performances of farm groups. To overcome this limitation, the possibility of integrating our approach into existing, representative farm information systems should be further explored. One example would be the FADN, which aims to be representative with regard to the FADN region, economic size and type of farming. This corresponds to the need identified by Kelly et al. (2018) of complementing FADN data with social and environmental indicators, although they also caution that the sampling concept of FADN needs to be reviewed when doing so.

## 5 Conclusion

The combined sustainability assessment indicates that the agro-ecological farms investigated contribute positively to biodiversity and water quality, whereas no clear pattern was observed regarding their impacts on soil quality. With regard to greenhouse gases, in some cases, agro-ecological farms have lower N-fertiliser application rates, which contributes to a reduction of emissions. However, a few agro-ecological practices also lead to higher emissions, for example, due to an increased use of fuel as a consequence of mechanical weeding. Contrary to the literature, we could not identify generally higher economic profitability of agro-ecological farms.

Although the application of the SAT was affected by practical challenges, the combination of approaches enabled an assessment of the status quo across different farming systems in Europe. In turn, this made it possible to identify general areas which could be improved, such as the need for a greater emphasis on integrating biodiversity conservation efforts into agricultural policy. The results also provide indications of prospective benefits of practices such as composting which could be promoted under the future Eco-schemes.

The assessment approach used in this study was characterised by its analytical strengths. However, there were challenges in applying the tools in the case studies. In subsequent applications, the tools could be improved by better integrating system boundary definitions and cut-off criteria for farm-level assessments. Given the advantages of combining different SATs, we identified the need for standardisation of the exchange of data between tools, which would facilitate improvements in future combined assessments.

In addition, a future study should explore the potential of including the combined assessment into existing, representative monitoring systems such as FADN. By implementing such improvements, the broad and interdisciplinary approach of the combined sustainability assessment provides results which can be of direct relevance for informing the development of policy and measures in national and regional agricultural and environmental strategies.

## Acknowledgements

This paper is based on results from the research project UNISECO, which is funded by European Union's Horizon 2020 research and innovation programme under grant agreement No. 773901.

We would like to thank all the farmers, farm organisations and stakeholders of the multi-actor platforms of the UNISECO project who contributed to the data collection. We also like to thank Andreas Basler whose corrections improved the comprehensibility of the paper.


## Supplementary materials

This article has two supplements attached:
S1: Overview of SAT indicators
S2: Case Study Report Structure

### REFERENCES


Adl SM, Coleman DC, Read F (2006) Slow recovery of soil biodiversity in sandy loam soils of Georgia after 25 years of no-tillage management. Agr Ecosyst Environ 114:323–334, doi:10.1016/j.agee.2005.11.019

Alliance Environnement (2019) Evaluation of the impact of the CAP on habitats, landscapes, biodiversity - Final Report

Altieri MA, Nicholls CI, Montalba R (2017) Technological approaches to sustainable agriculture at a crossroads: An agroecological perspective. Sustainability 9:349, doi:10.3390/su9030349

Arulnathan V, Heidari MD, Doyon M, Li E, Pelletier N (2020) Farm-level decision support tools: A review of methodological choices and their consistency with principles of sustainability assessment. J Clean Prod 256:120410, doi:10.1016/j.jclepro.2020.120410

Beaudoin N, Saad JK, Van Laethem C, Machet JM, Maucorps J, Mary B (2005) Nitrate leaching in intensive agriculture in Northern France: Effect of farming practices, soils and crop rotations. Agr Ecosyst Environ 111:292–310, doi:10.1016/j.agee.2005.06.006

Besser T, Mann S (2015) Which farm characteristics influence work satisfaction? An analysis of two agricultural systems. Agr Syst 141:107–112, doi:10.1016/j.agsy.2015.10.003

Biemer PP, Groves RM, Lyberg LE, Mathiowetz NA, Sudman S (2013) Measurement errors in surveys. John Wiley & Sons

Billeter R, Liira J, Bailey D, Bugter R, Arens P, Augenstein I, Aviron S, Baudry J, Bukacek R, Burel F et al. (2008) Indicators for biodiversity in agricultural landscapes: a pan-European study. J Appl Ecol 45:141–150, doi:10.1111/j.1365-2664.2007.01393.x

Binder CR, Feola G, Steinberger JK (2010) Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. Environ Impact Asses 30:71–81, doi:10.1016/j.eiar.2009.06.002

Bockstaller C, Feschet P, Angevin F (2015) Issues in evaluating sustainability of farming systems with indicators. OCL 22:D102, doi:10.1051/ocl/2014052

Bouttes M, Bancarel A, Doumayzel S, Viguié S, Cristobal MS, Martin G (2020) Conversion to organic farming increases dairy farmers' satisfaction independently of the strategies implemented. Agron Sustain Dev 40:12. doi:10.1007/s13593-020-00616-5

Campbell B, Beare D, Bennett E, Hall-Spencer J, Ingram J, Jaramillo F, Ortiz R, Ramankutty N, Sayer J, Shindell D (2017) Agriculture production as a major driver of the Earth system exceeding planetary boundaries. Ecol Soc 22(4):8, doi:10.5751/ES-09595-220408

CFA (2019a) The Cool Farm Tool | Cool Farm Tool [online]. Retrieved from <https://coolfarmtool.org/coolfarmtool/> [at 26 Oct 2019]

CFA (2019b) Biodiversity | Cool Farm Tool [online]. Retrieved from. <https://coolfarmtool.org/coolfarmtool/biodiversity/> [at 26 Oct 2019]

CLM (2019) In: GAIA Biodiversity Yardstick [online]. Retrieved from <https://gaia-biodiversity-yardstick.eu/> [at 26 Oct 2019]

Coteur I, Marchand F, Debruyne L, Dalemans F, Lauwers L (2016) A framework for guiding sustainability assessment and on-farm strategic decision making. Environ Impact Assess 60:16–23, doi:10.1016/j.eiar.2016.04.003

Coteur I, Wustenberghs H, Debruyne L, Lauwers L, Marchand F (2020) How do current sustainability assessment tools support farmers' strategic decision making? Ecol Indic 114(106298), doi:10.1016/j.ecolind.2020.106298

Crowder DW, Reganold JP (2015) Financial competitiveness of organic agriculture on a global scale. PNAS 112:7611–7616, doi:10.1073/pnas.1423674112

de Olde EM, Moller H, Marchand F, McDowell RW, MacLeod CJ, Sautier M, Halloy S, Barber A, Benge J, Bockstaller C et al. (2017) When experts disagree: the need to rethink indicator selection for assessing sustainability of agriculture. Environ Dev Sustain 19:1327–1342, doi:10.1007/s10668-016-9803-x

Duru M, Therond O, Fares M (2015) Designing agroecological transitions; A review. Agron Sustain Dev 35:1237–1257, doi:10.1007/s13593-015-0318-x

EEA/FOEN (2020) Is Europe living within the limits of our planet? - An assessment of Europe's environmental footprints in relation to planetary boundaries. Kopenhagen: European Environment Agency, Office of the European Union, 61 p, EEA Report 1/2020

Emmerson M, Morales MB, Oñate JJ, Batáry P, Berendse F, Liira J, Aavik T, Guerrero I, Bommarco R, Eggers S et al. (2016) Chapter Two - How agricultural intensification affects biodiversity and ecosystem services. In: Dumbrell AJ, Kordas RL, Woodward G (eds) Advances in Ecological Research. Academic Press, pp 43–97, doi:10.1016/bs.aecr.2016.08.005

European Court of Auditors, (2017), Special Report n°21/2017: Greening: a more complex income support scheme, not yet environmentally effective.

European Parliament, (2020) Financing of the CAP | Fact Sheets on the European Union | [online]. European Parliament. Retrieved from <https://www.europarl.europa.eu/factsheets/en/sheet/106/financing-of-the-cap> [at 19 Aug 2020]

European Union (2020) Farm to Fork Strategy - For a fair, healthy and environmentally-friendly food system [online]. Retrieved from < https://ec.europa.eu/food/farm2fork_en> [at 15 Dec 2020]

FADN (2018) Farm accountancy data network. An A to Z of methodology [online]. Retrieved from <https://ec.europa.eu/agriculture/rica/pdf/site_en.pdf> [at 21 Oct 2020]

FAO (2013) SAFA Guidelines Version 3.0. Food and Agriculture Organization of the United Nations (FAO)

Gasparatos A, El-Haram M, Horner M (2008) A critical review of reductionist approaches for assessing the progress towards sustainability. Environ Impact Asses 28:286–311, doi:10.1016/j.eiar.2007.09.002

Hatt S, Artru S, Brédart D, Lassois L, Francis F, Haubruge E, Garré S, Stassart PM, Dufrêne M, Monty A (2016) Towards sustainable food systems: the concept of agroecology and how it questions current research practices. A review. Biotechnol Agron Soc 20:215–224, doi:10.25518/1780-4507.12997

Hill SB, MacRae RJ (1996) Conceptual framework for the transition from conventional to sustainable agriculture. J Sustain Agr 7:81–87, doi:10.1300/J064v07n01_07

Hillier J, Walter C, Malin D, Garcia-Suarez T, Mila-i-Canals L, Smith P (2011) A farm-focused calculator for emissions from crop and livestock production. Environ Modell Softw 26:1070–1078, doi:10.1016/j.envsoft.2011.03.014

HLPE (2019) Other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security: Rome, Italy

ILO (1998) ILO declaration on fundamental principles and rights at work and its follow-up: Adopted by the International Labour Conference at its 86th Session, Geneva, 18 June 1998. International Labour Organization

IPCC (1997) An introduction to simple climate models used in the IPCC Second Assessment Report. WMO

IPES-Food (2016) From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems

Janker J, Mann S (2020) Understanding the social dimension of sustainability in agriculture: a critical review of sustainability assessment tools. Environ Dev Sustain 22:1671–1691, doi:10.1007/s10668-018-0282-0

Kelly E, Latruffe L, Desjeux Y, Ryan M, Uthes S, Diazabakana A, Dillon E, Finn J (2018) Sustainability indicators for improved assessment of the effects of agricultural policy across the EU: Is FADN the answer? Ecol Indic 89:903–911, doi:10.1016/j.ecolind.2017.12.053

Krause J, Machek O (2018) A comparative analysis of organic and conventional farmers in the Czech Republic. Agr Econ 64 (2018):1–8, doi:10.17221/161/2016-AGRICECON

Landert J, Pfeiffer C, Carolus J, Albanito F, Mueller A, Baumgart L, Blockeel J, Schwarz G, Waisshaidinger R, Bartel-Kratochvil R et al. (2019) Database on the performance of current Agro-Ecological Farming Systems (AEFS) as an input to the modelling in WP4. doi:10.5281/zenodo.3593989

Lechenet M, Dessaint F, Py G, Makowski D, Munier-Jolain N (2017) Reducing pesticide use while preserving crop productivity and profitability on arable farms. Nat Plants 3:1–6, doi:10.1038/nplants.2017.8

Leventon J, Schaal T, Velten S, Dänhardt J, Fischer J, Abson DJ, Newig J (2017) Collaboration or fragmentation? Biodiversity management through the common agricultural policy. Land Use Policy 64:1–12, doi:10.1016/j.landusepol.2017.02.009

Martínez-Blanco J, Lazcano C, Christensen TH, Muñoz P, Rieradevall J, Møller J, Antón A, Boldrin A (2013) Compost benefits for agriculture evaluated by life cycle assessment. A review. Agron Sustain Dev 33:721–732, doi:10.1007/s13593-013-0148-7

Meuwissen MPM, Mey Y de, van Asseldonk M (2018) Prospects for agricultural insurance in Europe. Agricultural Finance Review 78:174–182. doi:10.1108/AFR-04-2018-093

Migliorini P, Wezel A (2017) Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review. Agron Sustain Dev 37:63, doi:10.1007/s13593-017-0472-4

Mzoughi N (2014) Do organic farmers feel happier than conventional ones? An exploratory analysis. Ecol Econ 103:38–43, doi:10.1016/j.ecolecon.2014.04.015

Ogle SM, Alsaker C, Baldock J, Bernoux M, Breidt FJ, McConkey B, Regina K, Vazquez-Amabile GG (2019) Climate and soil characteristics determine where no-till management can store carbon in soils and mitigate greenhouse gas emissions. Sci Rep 9:11665, doi:10.1038/s41598-019-47861-7

Otero I, Farrell KN, Pueyo S, Kallis G, Kehoe L, Haberl H, Plutzar C, Hobson P, García-Márquez J, Rodríguez-Labajos B et al. (2020) Biodiversity policy beyond economic growth. Conserv Lett 13:e12713. doi:10.1111/conl.12713

Pe'er G, Bonn A, Bruelheide H, Dieker P, Eisenhauer N, Feindt PH, Hagedorn G, Hansjürgens B, Herzon I, Lomba Â, et al. (2020) Action needed for the EU Common Agricultural Policy to address sustainability challenges. People and Nature 2(2):305–316, doi:10.1002/pan3.10080

Pe'er G, Dicks LV, Visconti P, Arlettaz R, Báldi A, Benton TG, Collins S, Dieterich M, Gregory RD, Hartig F et al (2014) EU agricultural reform fails on biodiversity. Science 344:1090–1092, doi:10.1126/science.1253425

Pe'er G, Zinngrebe Y, Hauck J, Schindler S, Dittrich A, Zingg S, Tscharntke T, Oppermann R, Sutcliffe LME, Sirami C et al. (2017) Adding some green to the Greening: Improving the EU's ecological focus areas for biodiversity and farmers. Conserv Lett 10:517–530. doi:10.1111/conl.12333

Pintér L, Hardi P, Martinuzzi A, Hall J, (2012), Bellagio STAMP: Principles for sustainability assessment and measurement. Ecol Indic 17:20–28, doi:10.1016/j.ecolind.2011.07.001

Prazan J, Aalders I (2019) Typology of agro-ecological farming systems and practices in the EU and the selection of case studies [online]. Deliverable Report D2.2, UNISECO project, retrieved from <doi:10.5281/zenodo.4116344> [at 15 Dec 2020]

Röös E, Fischer K, Tidåker P, Nordström Källström H, (2019), How well is farmers' social situation captured by sustainability assessment tools? A Swedish case study. Int J Sust Dev World 26:268–281, doi:10.1080/13504509.2018.1560371

Sanz-Cobena A, Lassaletta L, Aguilera E, Prado A del, Garnier J, Billen G, Iglesias A, Sánchez B, Guardia G, Abalos D et al. (2017) Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review. Agric Ecosyst Environ 238:5–24, doi:10.1016/j.agee.2016.09.038

Sauvant D, Tran G, Heuzé V, Bastianelli D, Archimède H (2013) Feedipedia: une encyclopédie mondiale des ressources alimentaires pour les animaux d'élevage

Schader C, Baumgart L, Landert J, Muller A, Ssebunya B, Blockeel J, Weisshaidinger R, Petrasek R, Mészáros D, Padel S et al. (2016) Using the Sustainability Monitoring and Assessment Routine (SMART) for the systematic analysis of trade-offs and synergies between sustainability dimensions and themes at farm level. Sustainability 8:274, doi:10.3390/su8030274

Schader C, Grenz J, Meier M, Stolze M (2014) Scope and precision of sustainability assessment approaches to food systems. Ecol Soc 19(3):42, doi:10.5751/ES-06866-190342

Sirami C, Gross N, Baillod AB, Bertrand C, Carrié R, Hass A, Henckel L, Miguet P, Vuillot C, Alignier A et al. (2019) Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. PNAS 116:16442–16447, doi:10.1073/pnas.1906419116

Smith LG, Williams AG, Pearce BD (2015) The energy efficiency of organic agriculture: A review. Renew Agr Food Syst 30(3):280-301, doi:10.1017/S1742170513000471

Tittonell P (2014) Ecological intensification of agriculture—sustainable by nature. Curr Opin Env Sust 8:53–61, doi:10.1016/j.cosust.2014.08.006

van der Ploeg JD, Barjolle D, Bruil J, Brunori G, Costa Madureira LM, Dessein J, Drąg Z, Fink-Kessler A, Gasselin P, Gonzalez de Molina M et al. (2019) The economic potential of agroecology: Empirical evidence from Europe. J Rural Stud 71:46–61, doi:10.1016/j.jrurstud.2019.09.003

Viaene J, Van Lancker J, Vandecasteele B, Willekens K, Bijttebier J, Ruysschaert G, De Neve S, Reubens B (2016) Opportunities and barriers to on-farm composting and compost application: A case study from northwestern Europe. Waste Manage 48:181–192, doi:10.1016/j.wasman.2015.09.021

Wezel A, Bellon S (2018) Mapping agroecology in Europe. New developments and applications. Sustainability 10:2751, doi:10.3390/su10082751

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

Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet 393:447–492, doi:10.1016/S0140-6736(18)31788-4

RESEARCH ARTICLE

# How do policy-influential stakeholders from the Madrid region (Spain) understand and perceive the relevance of agroecology and the challenges for its regional implementation?

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Received: March 31, 2020
Revised: August 7, 2020
Revised: December 22, 2020
Accepted: December 23, 2020

HIGHLIGHTS

- **We studied the agroecological understanding and impact in the Madrid region.**
- **Four participatory workshops were conducted with policy-influential stakeholders**
- **Agroecological meaning was associated predominantly with environmental elements.**
- **Agroecology needs to be institutionalised, strengthening the productive sector in connection with local consumers.**

KEYWORDS **agroecology, agroecosystem, decision-making, multifunctional landscape, participatory workshop, rural development, transition**

## Abstract

Due to the high population growth rates and the negative impacts of the current agrifood production model, alternatives emerge to feed the current and future world population in a sustainable way. One of the proposed approaches is agroecology, understood as a scientific discipline, a set of agricultural practices and a socio-political movement that enhances the sustainability of agroecosystems from a holistic perspective. Agroecology was born and grew along the 20th century, and nowadays it is gaining legitimacy at different levels. However, agroecology is still an unknown concept in several influential fields. This paper attempts to study the impact of agroecology in the Madrid region and the main challenges and strategies to encourage its transition. We analysed the understanding and perceived challenges of the agroecological transitions of stakeholders whose role is crucial in the political sphere, through four participatory workshops conducted in October-November 2019 (n=79 attendees). Among the main findings it is remarkable the high agroecological understanding of the attendees. This concept is predominantly associated with environmental elements with less relevance of social and governance elements. One of the major challenges to be tackled is the lack of legal framework on agroecological issues. Additionally, consumers were considered essential as they contribute to the creation of demand for agroecological products, yet, the small productive sector is working precariously. Thus, the communication with these producers must be enhanced as well as their profession dignified. The institutionalisation of agroecology and the implementation of public policies are decisive factors for the agroecological transition.

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## 1 Introduction

Demographic projections hold that in 2050 the world's population will be $9.7 \cdot 10^9$ people. In response to the population's demand for food, a highly productive agroindustrial model has been promoted for decades following the Green Revolution (Borlaug, 1971). Recently, however, the academic, political and activist world are working to find alternatives to this model in order to feed the current and future population in an environmentally sustainable and socially equitable manner (Gliessman, 2015). Likewise, according to Delgado Cabeza (2010), the current agrifood system is not capable of feeding the entire world population either, since there are still problems related to hunger and malnutrition. The prevailing agroindustrial model has not paid enough attention to the negative social and environmental consequences of its production system (McIntyre et al., 2009). Indeed, this system has been characterised by the marginalisation of family farming with low capital and land, the abolition of subsistence agriculture, the loss of cultural identity, knowledge, traditional agricultural practices, the decline of (agro)biodiversity, soil contamination, overuse of inputs, soil degradation, the intensification of climate change and the impact on consumer health, among other impacts (Tilman, 1999; Delgado Cabeza, 2010; García-Llorente et al., 2019).

Although there are many alternative approaches proposed by science, agroecology has been considered as a possible solution to the above-mentioned problems (Anderson et al., 2015; Gliessman 2015, Gliessman 2020). According to Altieri (1999), agroecology is understood as the application of ecological concepts and principles to the design and management of sustainable agroecosystems. In this way, several fields of knowledge have focused on understanding agroecology as a natural scientific discipline and have researched its contribution to the sustainability of agroecosystems (Altieri 2002; Kremen and Miles, 2012; Wezel et al., 2014; Altieri et al., 2015). Altieri (2002) remarked the role of agroecology as a natural science able to provide the scientific basis to combine diverse and productive agroecosystems by embracing and understanding their complex ecological structure and function. Its practical implementation has been proved to be more effective than conventional practices in conserving biodiversity and supplying a wide variety of ecosystem services. Examples of this are: a more efficient use of carbon substrates (Chavarria et al., 2018), the possibility of intercropping to provide pest and weed control (Francis, 1986); improvement of nitrogen content in soil by intercropping legumes (Malézieux et al., 2009); or climate regulation through the use of grass strips to increase soil organic carbon stock (Van Vooren et al., 2018).

Additionally to the understanding of agroecology as a natural scientific disciple that studies the productive system, Wezel et al. (2009) claim in their work that agroecology is also considered a set of principles and practices that promote the ecological, socio-economic and cultural resilience of agricultural systems and a social movement that seeks a different way of considering agriculture and its relation with society. According to Wezel et al. (2009), in the 1920s the agroecology concept appeared as a scientific discipline combining agronomy and ecology. It was in the 1970s that its mainstream expansion took place. The term agroecology appeared for the first time in the scientific literature and it began to be considered not only as a discipline with theoretical approach, but also as a set of practices. During the 1980s, such agroecological practices were adopted by numerous social movements as an alternative to industrial agriculture (Sicili, 2014). As mentioned by Sourisseau et al. (2018), the different understandings of agroecology reflect the current debate on the future of agriculture in our society. Some definitions of agroecology are more technical and closer to the organic farming certification and the productive dimension. Meanwhile, others are more focused on the role of social movements, collective action and peasant-to-peasant knowledge (Markelova and Meinzen-Dick 2009; Altieri et al., 2012). Since different definitions of agroecology exist, Gallardo-López et al. (2018) have analysed how the concept has evolved over time, finding that agroecology is mainly considered as a science, as a practice and to a lesser degree as a social movement. Indeed, they suggest that a more equal relationship among these three components could boost the understanding of agroecology as an interdisciplinary concept. In this manuscript, we understand agroecology as a holistic concept that aims to contribute to the transition towards social-ecological sustainability. In this context, we embrace the wide definition provided by the Food and Agriculture Organization of the United Nations (FAO, 2018) which considers that to define agroecology accepting its holistic character (i.e., integrating ideas from various disciplines, understanding agroecology as a whole, going beyond the individual collection of parts), 10 elements must be taken into account: diversity, co-creation and sharing of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food transitions, responsible governance and circular and solidarity economy. In this study, we aim to analyse the understanding of agroecology from the policy-influential stakeholders' perspective, as an essential stakeholder group for the recognition of agroecology at the policy level.

In this regard, within the recent past, agroecology has been gradually legitimised at a global level, being recognised by the FAO in 2018. The organisation created an initiative called Scaling up Agroecology, which highlights the relevance of agroecology, showing how it can be a key to meeting the Sustainable Development Goals (SDGs) set out in the 2030 agenda (FAO, 2018). The Scaling up Agroecology initiative focuses on broadening the political impact of agroecology, due to the lack of agroecological awareness among decision-makers and the absence of political and economic support when it comes to prioritising sustainable approaches.

In Spain, agroecology is on the path of being scientifically recognised. As a matter of fact, the Spanish Association of Terrestrial Ecology (AEET) has created an agroecology research network. There are also research lines, academic groups and high education options that are becoming relevant in the study and teaching of agroecology (Wezel et al., 2018; Acosta-Naranjo et al., 2019). Agroecology is also gaining more support in the political sphere in Spain. In this sense, on November 20, 2018 a proposal concerning the application of agroecology to achieve the SDGs was presented in the Congress of Deputies (Boletín Oficial de las Cortes Generales, 2018). Additionally, in 2010 Red TERRAE (Network of Agroecological Reserve Territories) was born, a partnership of Spanish Municipalities involving different stakeholders to promote agricultural biodiversity and employment generation. However, the main principles of agroecology are not reflected in the public policies of the Community of Madrid, neither in the agrifood production system nor in the demands of consumers. Oteros-Rozas et al. (2019) state that the implementation of agroecological measures by public authorities is still at its early stage and should be encouraged. These same authors consider that agroecology is still an unknown concept in many influential areas (e.g. health, food, tourism, education).

In this context, the project 'AgroecologiCAM: Uncovering agroecology as a model of local farming and as a strategy for the design of local agrifood systems' was born. The project understands agroecology as a proposal of transition towards a more sustainable, healthy and fair agrarian model and agrifood system (http://agroecologicam.org/). The general objective of the AgroecologiCAM project is to address the barriers that are holding back the development of agroecology in the Madrid region. It is a three-year project (2018–2021) and it is implemented by an Operational Group (OG)promoted by the Rural Development Programme (RDP) of the Community of Madrid (2014–2020); Measure 16 of Cooperation (PDR Madrid, 2017). The OG AgroecologiCAM (2019) deals with the following three dimensions and goals: (1) knowledge, by extending the scientific and technical agroecological knowledge, (2) policy, by providing a space of dialogue and discussion to technicians, public administration managers and decision-makers to increase the institutional and social recognition of agroecology; and (3) dissemination, by making visible the role of the productive sector and raising consumers' awareness of agroecological products.

Within the AgroecologiCAM project, the general objective of this paper is to analyse the understanding and impact of agroecology in the Madrid region by involving technicians, managers, decision-makers, etc., identified as policy-influential stakeholders in the design, implementation or evaluation of policies. We refer to the term understanding of agroecology to analyse the meaning or conceptualisation of agroecology held by policy-influential stakeholders, since there is not a unified definition of agroecology and their view will determine their actions. The term impact of agroecology refers to the incidence agroecology has in the political agenda including related barriers and challenges as perceived by the attendees. To deal with this objective, we conducted the next two tasks: (1) assess the conceptualisation of agroecology and its association with environmental, economic, sociocultural and governance components of the agrarian model and the agrifood system; and (2) explore the perceptions regarding the main barriers and challenges for a greater impact of agroecology on the future political agenda. Hence, by our investigation we attempt to respond to the following research questions in the context of the Madrid region: How do influential stakeholders understand agroecology? What do they know about agroecology and the different elements of the agroecosystems? What has still to be done to promote an agroecological transition in the Madrid region? This information is intended to better understand the meaning of agroecology for policy-influential stakeholders in the Madrid region, to later facilitate political support to design agroecological strategies that foster the future transition of the agrarian model and the agrifood system in the region.

## 2 Material and methods

### 2.1 Study area

The project is linked to the development and fostering of agroecology in the region of Madrid, which is administratively defined as the Community of Madrid, and especially in the rural territories of the region. The Madrid region occupies an area of 8028 km$^2$ with a population of 6.7 million of inhabitants (for 2019) distributed in 179 municipalities. Madrid city hosts almost half of its total population and, as other European capitals, its metropolitan power leads to a minority of rural areas and a modest territory dedicated to agricultural activities: 28 % agricultural land and 7 % pastureland (del Valle et al., 2018). Madrid rural areas are divided in three regions: north (19 municipalities), southwest (42 municipalities), and southeast (23 municipalities; *Figure 1*). For a good representation of stakeholders from a large diversity of rural territories we held three participatory workshops in three municipalities of each rural territory to encourage the attendance of representatives from the three rural areas. The fourth participatory workshop was held in the Gastronomic Innovation Center of Madrid city, in order to encourage the attendance

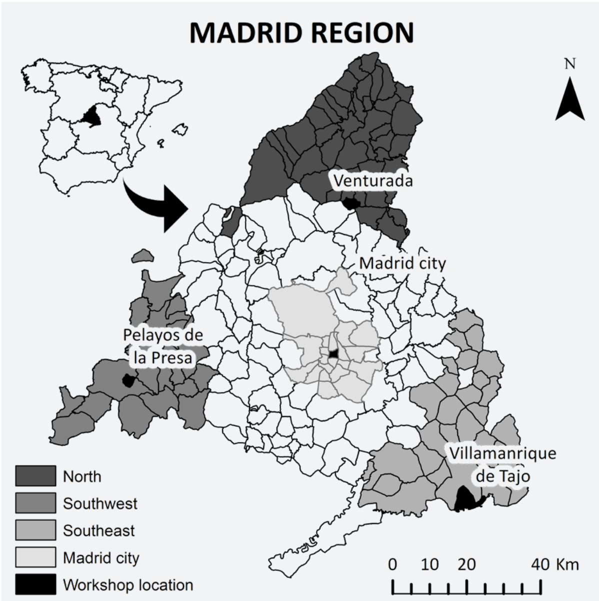


**FIGURE 1**
Rural municipalities of the Madrid region, classified by area (north, southwest and southeast) and location of the four participatory workshops, including Madrid city

of technicians, managers of the public administration and decision-makers who develop their professional activity in the headquarters in Madrid city, such as the Regional Government of the Environment, Territorial Planning and Sustainability.

## 2.2 Recruitment and characterisation of attendees

The sample was composed of technicians, managers, landscape planners, decision-makers, and other public staff from the local and regional government of the Madrid region related with the development of public food, rural, agricultural and landscape planning policies. In addition, the recruitment of attendees also considered other influential stakeholders from the academic, educational, and environmental sectors (*Figure 2*).

In order to advertise the event, we notified Madrid city councils by e-mail including an informative digital leaflet and posters containing relevant information of the participatory workshops. Announcements were also published on the websites of the project (agroecologicam.org), the Madrid City Council (madrid.org), the Community of Madrid (comunidad.madrid) and other web pages for the agroecological transition in Madrid such as agrolabmadrid.com, observatorioculturayterritorio.org, agroecología.net, and tierrasagroecologicas.es. We also sent personal invitations to policy-influential contacts we already knew from the AgroecologiCAM project network. Additionally, we contacted the Local Action Groups of the three rural territories of the Community of Madrid who contributed to disseminate the call.

An important recruitment effort was done; nevertheless, some limitations regarding the open sample selection must be considered such as the over or infra representation of perspectives (Harrison, 2013). Since the participatory workshops were voluntary, we probably missed policy-influential stakeholders with decision-making capacity in the development of public food rural, agricultural and landscape planning policies but without an interest, or even with reluctant positions, in agroecological approaches to reframe the conventional farming system. We assume that the people who finally took part in the workshops were the ones that decided freely to attend, and that were mostly interested in the topic, because of either their high knowledge or their interest to learn about it. This attendees' profile is the one that could best contribute and enhance the understanding of the phenomenon under study (Creswell, 2008). Further research could be enriched by combining the information extracted from the participatory workshops with personal interviews with the missing policy-influential stakeholders. Another potential bias of the open invitation is that the number of attendees is not predetermined. To tackle this shortcoming, a recommended but not compulsory pre-registration was done. In addition, four facilitators assisted each session, and a plan for working in break-out groups was designed. Finally, as in any participatory activity, there was a risk of experiencing power asymmetries in the deliberation process by the attendance of dominant attendees leading the discourse. To minimise this, the participatory workshops were moderated and speaking times were carefully given.

Overall, the participatory workshops were attended by 79 attendees (8 people in two of the rural municipalities, 32 in the third rural participatory workshop, and 31 people in the participatory workshop organised in Madrid city); of those, 42 responded the written questionnaire (7 people in the first rural municipality, 6 people in the second rural municipality, 11 people in the third rural municipality, and 18 people in the participatory workshop organised in Madrid city).

The respondents were 23 men and 19 women. Most of them were between 40 and 60 years old and 36 (85 %) of them had received university education. Some similarities

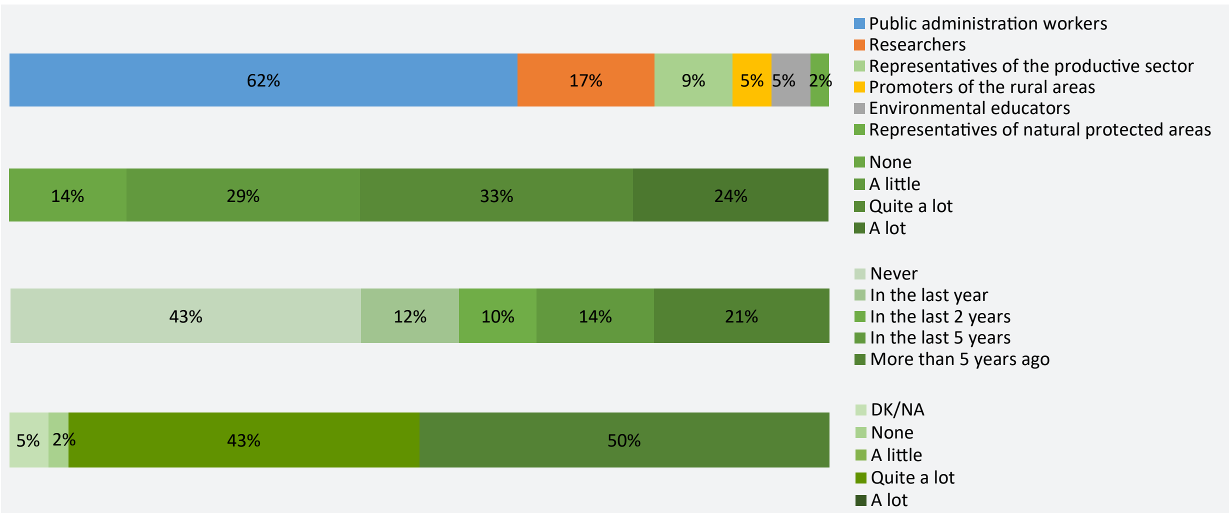


FIGURE 2

Characterisation of the respondents' profile (n=42): (A) professional role; (B) professional linkage to agroecology; (C) time since the concept was incorporated into their professional activity; and (D) level of importance of integrating agroecology into public policy design at different scales according to the respondents.

have been found with a study carried out by Migliorini et al. (2017) that assessed the perception, definition and future expectations of different stakeholders regarding agroecology and organic agriculture. In both cases, the public stands out for its knowledge and interest in agroecology (*Figure 2*). Although the participatory workshops were mainly focused on stakeholders from the public administration, researchers have shown their interest on agroecology with their participation (*Figure 2: A*). This fact can be explained by Wezel et al. (2018), who argue that research and education are currently major components of agroecology in Europe. In this paper, part of the researchers who attended the event were aware of it because of their link to the AgroecologiCAM project. Additionally, it is important to stress the fact that 24 (57 %) respondents have incorporated agroecology into their professional activity (19 (80 %) of them have been doing so for more than two years; *Figure 2: B, C*). With regard to their motivation to take part in the participatory workshops, the interest in agroecological practices for the development of rural municipalities was the dominant factor (9 respondents; 21 %); others participated because they considered important the promotion of agroecology (8 respondents; 19 %) or in order to incorporate it in their work (8 respondents; 19 %); 6 respondents (14 %) attended because they were interested; 3 respondents (7 %) participated with the objective of acquiring knowledge of effective agroecological practices and to form networks with different stakeholders; the same number of people (3 respondents; 7 %) participated because they were members of the AgroecologiCAM project; and the remaining 2 respondents (5 %) participated because they wanted to include agroecology in Environmental Education. Finally, the written questionnaire showed that 39 (93 %) of the respondents considered the integration of agroecology into public policies necessary (*Figure 2: D*).

## 2.3 Data collection

Data was collected in four participatory workshops held in the Madrid region through an attendant list, a questionnaire and from active debate during the participatory workshops. Participatory workshop is a consultative data collection method based on gathering primary and qualitative information provided by a group dynamic with selected stakeholders. The aim of this participatory workshops was to acquire information from the positions and discourses of the sample, but also to incentive social learning, sharing and co-creating knowledge among the group. Social learning has been recognised as a key feature for socioecological sustainability issues because it enhances understanding and promotes the creation of trustworthy relationships among stakeholders with different perspectives, interests and needs (Opdam et al., 2013; Karimi et al., 2015; García-Nieto et al., 2019). These workshops allowed us to bring together diverse knowledge holders to seek their opinions, extract their knowledge and identify and understand challenges and barriers to an agroecological transition in Madrid in collaborative and creative environments (Knapp et al. 2011).

At the beginning of each participatory workshop an attendant list was completed, including the organisation where they conduct their work and professional role; this information was relevant to characterise their profiles. All the information was collected anonymously and confidentially. Then, before starting the participatory workshop, attendees were asked to complete a questionnaire in order to gather information about their understanding of agroecology. As it has been noted previously, the number of respondents (n=42), attendants who answer the questionnaire, did not coincide with the number of participants (n=79) due to different reasons: those who arrived late to the participatory workshop did not respond, as the questionnaire had to be answered before the discussions began, those linked to the project did not respond either, and some attendees did not want/remember to respond to the questionnaire.

The questionnaire gathered personal information as well as information about their professional role, linkage to agroecology, motivations to participate and their agroecological understanding (*Table 1*). Additionally, 28 elements were given to analyse its importance and its relationship with agroecology covering ecological, sociocultural, economic and governance aspects (*Table 2*). Ten of the elements came from a selection made by FAO (2018a) described as the ten elements of agroecology: (1) human and social values of equity, inclusion and justice; (2) recycling of nutrients, biomass and water; (3) diversity of species, genetic resources and practices; (4) exchange of knowledge among producers; (5) efficiency in the use of products and energy; (6) synergies or synchronisation of production practices; (7) capacity to adapt to extreme events; (8) responsible governance; (9) circular economy that reconnects production and consumption; (10) culture, heritage and agrifood traditions. The remaining eighteen are also shown in *Table 2* and were selected in order to cover more aspects that characterise agroecology according to scientific documents on the discipline (Palomo-Campesino et al., 2018; Wezel et al., 2018). The selection of agroecological elements did not cover misleading elements, because the purpose of this section was to include elements which are, in fact, descriptors of agroecology. As agroecology is a complex and holistic concept, it has many different descriptors covering ecological, sociocultural, economic and governance aspects. Thus, we have investigated the conceptualisation that stakeholders with a strong influence on policy making have on these elements.

Finally, once the questionnaires were completed, the discussions of the participatory workshop were carried out consisting of the challenges of agroecology in five different areas: (1) productive systems and the opportunities of employment and maintenance of the rural environment; (2) mitigation and adaptation to climate change; (3) consumers' role and health; (4) institutions and public policies; and (5) strategies for the agroecological transition and the rural development of the Madrid region 2021-2027. Before the discussion of each topic, a presentation was made covering its theoretical aspects; afterwards, the attendees adopted the roles of analysts, with the aim of raising questions or reflections so that the key challenges linked to each of the subjects could be identified. This way, the attendees that had something to say participated one by one. Since the attendees were somehow linked to the

**TABLE 1**
Summary of questionnaire information: variables used, coding type and main attributes

| Variables | Coding type | Attributes |
|---|---|---|
| Professional role | Nominal | Characterisation of the respondent's professional profile |
| Organisation | Nominal | Organisation in which the respondent works |
| Level of education | Ordinal | 1, non-formal education; 2, with complete primary education; 3, with complete secondary education; 4, complete education; 5, professional education; 6, college degree |
| Age | Ordinal | Age of the respondent |
| Sex | Dichotomous | 1, woman; 0, man |
| Prof linkage | Ordinal | Application of agroecology in the work routine (1, none; 2, a little; 3, quite a lot; 4, a lot) |
| Years agroecology | Ordinal | How recently has agroecology been incorporated into the work routine (0, never; 1, in the last year; 2, in the last two years; 3, in the last 5 years; 4, more than 5 years ago) |
| Motivation | Nominal | Motivation for taking part in the participatory workshop |
| Policies | Ordinal | Level of importance of integrating agroecology into public policy design (1, none; 2, a little bit; 3, quite a lot; 4, a lot) |
| Agroecological understanding | Dichotomous | Agroecological understanding before the participatory workshop (1, yes; 0, no) |
| Definition | Nominal | Definition of agroecology |
| Term importance (28 terms) | Ordinal | Level of importance of different terms (1, not important - 10 highly important) |
| Term relation (28 terms) | Ordinal | Relationship between different terms and agroecology (1, unrelated - 10 closely related) |

agroecological development in the Madrid region, they were expected to identify local barriers and challenges of agroecology. Thereby, they could show their perspectives and give information about the situation of agroecology mainly in rural territories of the Madrid region.

The participatory workshops were facilitated by at least four people who introduced the AgroecologiCAM project, explained the five topics, enabled the active participation, controlled times, recorded audios, and took notes. They were experts in topics such as agroecological development, circular economy in agrifood systems, climate change, rural development, etc.; with a track record as facilitators in agroecological development processes. The audio obtained from these participatory workshops was recorded in digital devices.

### 2.4 Data analysis

The data obtained from the questionnaires (n=42) was entered in Microsoft Excel- using the parameters mentioned in data collection section- and analysed with the XLSTAT extension. By means of this data, a detailed descriptive analysis was carried out to analyse the agroecological understanding of the respondents; then, a scatter diagram was created to study the relationship between the importance given to certain elements and the relationship with agroecology that the respondents considered these elements to have. Then, data was analysed with the non-parametric Kruskal-Wallis test (Kruskal and Wallis 1952) with the aim of evaluating whether there were significant differences between the scores given by the respondents and the various elements of the agrarian model and the agrifood system. A Dunn test (Dunn 1964) was then performed to identify the groups of elements that did not show significant differences between them, with the objective of verifying the test performed previously and analysing which elements have similar patterns and from which ones they differ.

Finally, audio recordings of the participatory workshops discussions (n=79) were fully transcribed; interventions were firstly coded and secondly classified by topic and the resulting list was then exported to Atlas.ti, where the qualitative analysis was further conducted creating codes to be regrouped into families. Once the information was analysed, a diagram was created summarising the barriers and challenges of agroecology as perceived by those attending the participatory workshops.

## 3 Results

### 3.1 Agroecological knowledge and the relationship between agroecology and environmental, sociocultural, economic and governance elements of the agrarian model and the agrifood system

Overall, 36 respondents (86 %) already knew about the concept of agroecology before taking part in the participatory workshop. However, the conceptualisation of agroecology varies among them: 11 respondents (26 %) defined agroecology as a set of sustainable farming practices, 10 respondents (24 %) as a socially and environmentally sustainable production, 9 respondents (21 %) identified it as the application of ecology in agriculture, 5 respondents (12 %) considered it a holistic and multidisciplinary concept, and 2 respondents (5 %) defined agroecology as the necessary application of an urban-rural link.

**TABLE 2**
Importance of the 28 elements expressed by the respondents and the relationship the respondents considered these elements to have with agroecology (scoring levels from 1-not important/unrelated to 10-highly important/closely related). Arithmetic Mean, Standard Deviation and Dunn Groups are indicated.

| Elements of Agroecology | Importance | | | Relationship with agroecology | | |
|---|---|---|---|---|---|---|
| | Arithmetic mean | Standard deviation | Dunn groups* | Arithmetic mean | Standard deviation | Dunn groups* |
| Recycling of nutrients, biomass and water | 9.54 | 1.05 | c | 9.68 | 0.75 | b |
| Ecology and conservation of the environment | 9.51 | 1.12 | b-c | 9.59 | 0.90 | b |
| Circular economy that reconnects production and consumption | 9.29 | 1.13 | a-b-c | 9.33 | 1.01 | a-b |
| Efficiency in the use of products and energy | 9.27 | 1.12 | a-b-c | 9.24 | 1.21 | a-b |
| Human and social values of equity, inclusion and justice | 9.25 | 1.30 | a-b-c | 9.00 | 1.72 | b |
| Fertile and living soils | 9.24 | 1.14 | a-b-c | 9.57 | 0.77 | a-b |
| Healthy food | 9.15 | 1.11 | a-b-c | 9.16 | 1.28 | a-b |
| Rural development | 9.15 | 1.12 | a-b-c | 9.11 | 1.31 | a-b |
| Farm-to-table and short-circuit solutions | 9.07 | 1.21 | a-b-c | 9.05 | 1.35 | a-b |
| Environmentally sustainable consumption | 9.02 | 1.24 | a-b-c | 9.08 | 1.30 | a-b |
| Fresh and seasonal food | 9.00 | 1.20 | a-b-c | 9.16 | 1.36 | a-b |
| Organic farming | 8.98 | 1.51 | a-b-c | 9.23 | 1.33 | a-b |
| Maintenance of local varieties | 8.98 | 1.25 | a-b-c | 9.22 | 1.25 | a-b |
| Socially sustainable consumption | 8.90 | 1.32 | a-b-c | 8.72 | 1.6 | a-b |
| Multifunctional landscapes with productive, aesthetic, recreational, ecological value, etc. | 8.74 | 1.25 | a-b-c | 8.94 | 1.24 | a-b |
| Resiliency (capacity to adapt) to extreme events | 8.71 | 1.44 | a-b-c | 8.75 | 1.54 | a-b |
| Carbon fixation | 8.70 | 1.51 | a-b-c | 8.77 | 1.52 | a-b |
| Responsible governance | 8.69 | 1.49 | a-b-c | 8.25 | 1.92 | a-b |
| Culture, heritage and agrifood traditions | 8.68 | 1.46 | a-b-c | 8.78 | 1.61 | a-b |
| Collaboration between actors | 8.63 | 1.61 | a-b-c | 8.73 | 1.33 | a-b |
| Employment niche | 8.63 | 1.48 | a-b-c | 8.54 | 1.88 | a-b |
| Fight against rural depopulation | 8.62 | 1.87 | a-b-c | 8.57 | 1.85 | a-b |
| Diversity of species, genetic resources and practices | 8.59 | 1.65 | a-b-c | 8.89 | 1.57 | a-b |
| Food sovereignty | 8.46 | 1.68 | a-b-c | 8.60 | 1.82 | a-b |
| Synergies or synchronisation of production practices | 8.41 | 1.26 | a | 8.58 | 1.20 | a-b |
| Exchange of knowledge among producers | 8.39 | 1.51 | a-b | 8.54 | 1.45 | a-b |
| Citizen participation | 8.19 | 1.52 | a | 7.89 | 1.91 | a |
| Access to land | 8.00 | 1.86 | a | 8.26 | 1.79 | a-b |

* Dunn Groups collect sets of variables that are not significantly different from each other.

The importance and relationship with agroecology varied depending on the 28 elements proposed (*Table 2*). After the Kruskal-Wallis analysis, significant differences were found in the importance attached to the different elements (Kruskal-Wallis, K= 87.48; p-value<0.01), and their relationship with agroecology (Kruskal-Wallis, K= 83.36; p-value<0.01). On the one hand, dealing with the importance given by the respondents, recycling of nutrients, biomass and water (9.54, from a scoring from 1 to 10) was the most important element, followed by ecology and conservation of the environment (9.51) and circular economy that reconnects production and consumption (9.29). The ones with lower values were exchange of knowledge among producers (8.39), citizen participation (8.19) and access to land (8.00). In this sense, the groupings carried out by means of the Dunn test revealed that there were no significant statistical differences between most elements (a-b-c). The only exception was recycling of nutrients, biomass and water (c), which obtained a higher importance than both the exchange of knowledge among producers (a-b) and the following three elements: synergies or synchronisation of productive practices (a), citizen participation (a) and access to land (a) (all of them were not significantly different from each other; however, they did obtain significantly lower scores than recycling of nutrients, biomass and water). Only these last three elements were significantly different from ecology and environmental conservation (b-c). On the other hand, dealing with the relationship that the 28 elements have with agroecology, the following high scored elements are highlighted: recycling of nutrients, biomass and water (9.68), ecology and conservation of the environment (9.59) and fertile and living soils (9.57). While the elements considered with the lowest relationship with agroecology were access to land (8.26), responsible governance (8.25) and citizen participation (7.89). Citizen participation obtained a statistically significant lower value than the rest of the elements, having these obtained significantly similar scores to each other.

## 3.3 Barriers and challenges of agroecology

During the participatory workshops a total of 101 mentions were classified in five groups by topic and period of time. The five groups were: (1) productive systems and the opportunities of employment and maintenance of the rural environment; (2) mitigation and adaptation to climate change; (3) consumers' role and health; (4) institutions and public policies; and (5) strategies for the agroecological transition and the rural development of the Madrid region 2021-2027 (*Figure 3*).

Regarding the role of agroecological practices from the point of view of the productive system and the opportunities of employment and maintenance of the rural environment (f=19/101 mentions; *Figure 3*), the attendees remarked the absence of generational replacement and the lack of communication between producers, the economic low profitability of the sector due to lower yield, the insufficient employment generation and the loss of traditional values.

The challenges perceived in relation to the role of consumers for the agroecological transition were especially present during the participatory workshops (f=27/101 mentions; *Figure 3*). In fact, the attendees made numerous interventions regarding logistical aspects related to the need to develop information strategies to promote socially and environmentally responsible consumption, the need to change the prevailing consumption habits characterised by high fast food consumption and by the demand of more products from abroad, the risk of reproducing an agrifood system that only some privilege groups of people could afford, and the need to better connect food consumption with health. Even if the role of agroecology in dealing with climate change was the least-mentioned topic (f=10/101 mentions; *Figure 3)*, attendees mentioned barriers such as the lack of scientific evidence or the insufficient climate change awareness.

Several challenges were stated about institutions and public policies in the agroecological context (f=24/101 mentions; *Figure 3*). Indeed, attendees highlighted the lack of action of organizations and policies such as the World Health Organization (WHO), the Common Agricultural Policy (CAP), the Madrid Institute for Research and Rural, Agricultural and Food Development (IMIDRA), the Ministry of Ecological Transition, the state, autonomous and municipal Spanish governments. Other aspects stated regarding the role of institutions and public policies were the scare number of competences of local governments, or the absence of citizen participation

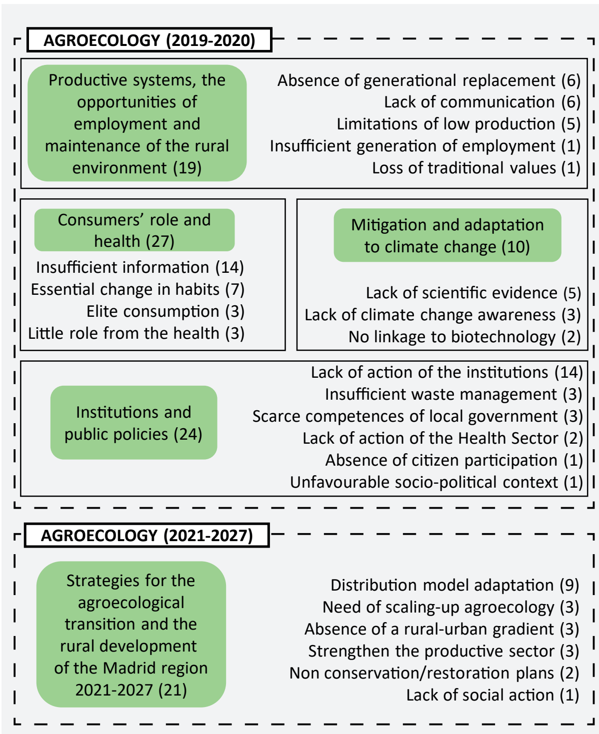


**FIGURE 3**
Barriers and challenges of agroecology perceived by the attendees (n=79) during the participatory workshops. Mentions have been classified into several themes, regrouped under five topics (green shaded) and divided in accordance with the period of time (2019/2020 and next programme period for the design of agrifood policies 2021–2027). The number of mentions is shown in parentheses.

in public policies, between others. Finally, the attendees identified some barriers that the agroecological transition could face in the future context of Madrid region (f=21/101 mentions; *Figure 3*), such as the need to adapt the distribution model by shortening the food supply chains, the need to scale-up agroecology, the need to promote an agroecological transition connecting urban-rural regions in Madrid, or the importance of consolidating the productive sector.

## 4 Discussion

A great majority of respondents already knew about the concept of agroecology before taking part in the participatory workshop. This result was expected, since the selected attendees were linked mainly to the policy-making sector (including public food, rural, agriculture and landscape planning policies) and, to the academic, educational, and environmental sectors.

Although the conceptualisation of agroecology varies among the respondents, all the definitions were complementary and emphasised different aspects of agroecology. Wezel et al. (2009) consider that the different interpretations of the concept depend on the set of contextual factors surrounding the individual. In this sense, Méndez et al. (2015) argue that by assuming the complexity of the term agroecology, the application of limited definitions is promoted, removing the interdisciplinary nature that characterises it.

Concerning the 28 environmental, sociocultural, economic and governance elements of the agrarian model and the agrifood system, it should be noted that the highest values were assigned to environmental elements while the lowest values were assigned to sociocultural (e.g. exchange of knowledge among producers) and governance (citizen participation, access to land) elements. This coincides with the systematic review conducted by Palomo-Campesino et al. (2018) in which it is shown that there are many more studies from natural scientific discipline than those that study sociocultural, economic or governance dimensions. One explanation that has contributed to this result is that the profile of the attendees was mainly linked to natural science disciplines such as Agronomy, Biology, Forestry or Environmental Sciences. This is reflected in the lower score of elements such as citizen participation or access to land, while both terms are considered by the academic world as essential points for a sustainable social, environmental and economic transition. For example, Altieri (2009) and Rossett et al. (2019), when describing La Via Campesina, highlight the involvement of this movement in the struggle for an agrarian reform that gives communities access and control over their land, in order to fulfil their demands. Likewise, it has been seen that agroecology is one of the possible ways to promote the development of rural areas and to deal with the problem of depopulation in rural Spain. On this matter, the Spanish Ministry of Territorial Policy and Public Function (2019) holds that the support for family farming is an essential measure to tackle rural depopulation, due to both its link with the territory and the fair distribution of wealth and employment it generates. For the reasons mentioned above, and since the attendees mainly came from rural municipalities, a high score was expected in elements such as rural development, fight against rural depopulation, or employment niche. Although it is true that they received high values, these were not among the highest rated elements.

Regarding the agroecological challenges associated to the productive side, it is worth mentioning the difficulty and precariousness of working in the field, as well as the need to dignify the producers' profession. The FAO (2018) considers a duty of agroecology to place the producers at the centre of the agrifood system, emphasising dignity, equity, inclusion and justice. This shift should be immediate, since there are alarming statistics that show the reduction of farmers in Spain in favour of other economic sectors or moving towards larger cities (Franco and Borras, 2013; Pinilla and Sáez, 2017; Acosta-Naranjo et al., 2019). The loss of traditional values and rural culture was highlighted as a threat by the attendees. Therefore, one of the points proposed by the FAO (2018) for the fulfilment of the SDGs through agroecology is to value the food heritage and local culture, promoting food security and at the same time respecting the ecosystems. At present, during the COVID-19 pandemic and health crisis, the need emerges to rethink the agrifood system and its vital role to feed the population in a healthy and sustainable way, promoting small-scale agroecological production (Gliessman, 2020). Another aspect mentioned by attendees was the lower productivity of agroecological plots. Despite this, the economic profitability of agroecological production has been proven, and there are studies that show the economic benefits provided by livestock and agricultural production through direct sales, agroecological canteens, or consumer groups (del Valle et al., 2018; Van der Ploeg et al., 2019). According to some attendees, the problem might arise from the lack of communication with the productive sector, since most small producers are unaware of these data. Indeed, Lucas and Gasselin (2018) investigate the "silent development" of agroecology, which is barely visible to conventional producers. Innovative agri-environment measures should be designed to focus on strengthening the economic viability and collaboration between the productive sector using agroecological practices either through collective approaches, support networks and other incentives from public or private sectors (Yacamán et al., 2020).

The data collected during the active participation and discussion at the participatory workshops demonstrated the vital role of consumers in demanding agroecological products. Indeed, Levidow et al. (2014) consider that the role of research is key to strengthening consumer support for agroecological production. In the same study, the authors mention the advantages of considering the opinions and tastes of consumers in order to create and increase agroecological knowledge, as well as the need to encourage consumer support for small food producers who are not certified. At the same time, the possibility of reaching this change in consumption habits through health should be considered, with the use of fresh, seasonal products and free of harmful substances. The FAO (2018) holds that the new markets that trade agroecological products represent an attempt to respond to the growing demand for healthier diets. Horrigan et al. (2002) consider that raising awareness about the serious health impacts of conventional agriculture is essential both in the short and long term (e.g. cardiovascular diseases, cancer risk, bioaccumulation of toxic substances in the body, etc.). Finally, attendees referred to the high price of agroecological products, since it can make agroecology unfeasible on a large scale due to its elitism of consumption (*Figure 3*). Concerning the link between agroecology and nutrition, Poux and Aubert (2018) have demonstrated that the implementation of widespread agroecological farming practices by 2050 could boost the adoption of healthier diets (e.g. reduction in meat consumption, or higher fibres intake) by European citizens.

The impact of agroecology as a tool for mitigation and adaptation to climate change was not particularly noticeable, but it was also considered. Scarborough et al. (2014) compare various diets in terms of greenhouse gas (GHG) emissions and found a huge difference, almost three times greater, between meat and vegetable-based diets. In addition, it is important to take into consideration the contribution of agroecological production in terms of carbon fixation, nutrient recycling and reduction of GHG emissions due to the proximity of consumption. Moreover, Altieri (2009) highlights the capacity of traditional agricultural systems to naturally increase productivity and resilience to changing climatic conditions. As argued by the FAO (2018), it is claimed that there is a need to expand scientific research on agroecology in order to gain evidence of its positive effects, thus creating a consolidated theoretical basis for the development of public policies.

The challenges perceived in relation to the role of institutions and public policies were numerous. Many organisations were mentioned for their inaction in agroecological issues, although they are essential for the promotion of agroecology (Oteros-Rozas et al., 2019). In this regard, one of the debates of the participatory workshops covered the possibility of learning from the French model, on which the CAP is based and that has already been implemented in the country through the Law d'Avenir (Law No. 2014-1170, 2014) "for the future of agriculture, food and forestry". The Law d'Avenir proposed a new agricultural model by combining economic, social and environmental considerations under an agroecological policy in which farmers' groups are considered (Bodiguel, 2014). It is claimed that one of the limitations of the law is the difficulty in developing indicators and evaluating tools to measure the reality of its implementation due to the diversity of definitions, practices and approaches that characterise agroecology (Claveirole, 2016). Similarly, some attendees stressed that the current socio-political context is not very favourable for the development of agroecology, due to the overall political and economic regime, and the inability of the local authorities to act due to their lack of competences. However, it was highlighted that various local government competencies, duties and responsibilities, can be used for the introduction of agroecological measures at the local level: parks and gardens, which can lead to the creation of urban homegardens; waste collection and management, where agro-composting initiatives can be created; consumption, markets and trade, such as the promotion of agroecological markets or healthy consumption campaigns; and culture, through the creation of agroecological training and leisure activities (Begiristain-Zubillaga, 2018; López-García et al., 2018; Cevallos-Suarez et al., 2019).

Overall, the attendees mentioned several aspects that should be considered by policy makers in order to promote the agroecological transition in the Madrid region; being the adaptation of the distribution model essential. There is a need of reforming the prevailing distribution model towards short food supply chains are required, from both a legislative and a logistic point of view. As Yacamán et al. (2020) state, knowledge, communication and public policies are key elements to boost the agroecological transition in Madrid. In relation to this and considering the important role given to consumers during the participatory workshops, the regional government must develop awareness-raising campaigns accompanied by the promotion of Madrid agrifood production in order to gain consumers' support in the agroecological market. By implementing these strategies, local agroecological production can take advantage of the proximity to the large food demand by the Madrid city. This implies establishing reliable producer-consumer connections. Likewise, Nicholls et al. (2016) highlights the importance of developing equal opportunities among producers based on networks, emphasising the creation of marketing and distribution schemes. Another aspect that must be considered by policy makers is the need to structure and reorganise marketing and distribution channels. These can be tackled through the creation of markets dedicated solely to the sale of organic products or by the development of platforms to join producers and consumers together (Germinando, 2019). To this end, Levidow et al. (2014) claim that numerous initiatives have already been implemented in Europe in order to bring producers and consumers closer together with the aim of creating agrifood networks and proximity trade. Finally, Mier et al. (2018) identified eight aspects that foster the scaling of agroecology, being mobilisation of discourse and the promotion of favourable public policies relevant components. In this research, we would like to take a first step forward towards the institutionalisation of agroecology in Madrid region by the establishment of a space of dialogue with policy-influential stakeholders in the design of agroecological policies.

## 5 Conclusions

The sample of this study – policy-influential stakeholders – shows a clear interest in and understanding of agroecological issues. The data obtained indicates the diversity of meanings of agroecology and the complexity of defining it (Wezel et al., 2009; Méndez et al., 2015). The agroecological knowledge has been predominantly associated with the environmental elements of agroecosystems (recycling of nutrients, biomass and water; and ecology and conservation of the environment) as opposed to the sociocultural, economic and governance components affecting the whole agrifood system. Despite the potential difficulties of not having a unified definition; it is important to embrace the plurality of the concept;

considering all its dimensions and its applicability in the whole agrifood system.

Regarding the barriers and challenges to an agroecological transition in the Madrid region, following our findings, from the productive side, it is essential to develop a variety of networks for the transmission of agroecological knowledge (Nicholls et al., 2016) and to understand the needs of the productive sector. Additionally, future strategies must focus on the demand side of consumers, which is deemed as an essential factor in fostering agroecological production (Levidow et al., 2014). This could be accomplished by analysing the public information promoting healthy and socio-environmentally sustainable modes of consumption and by strengthening the connexion between the productive sector and local consumers. In terms of the policy perspective, we highlight the absence of a legal framework in agroecology. The institutionalisation of agroecology, together with the implementation of public policies is a decisive factor for an agroecological transition. As Mier et al. (2018) remarked, the mobilisation of discourse and the promotion of favourable public policies are drivers to encourage the scaling up of agroecology; together with other aspects such as the moments of crisis, that foster the search of alternatives. Under the global change context and the health, economic and environmental crisis we are facing, it is time to support agroecological transitions. To do so, a coordination between the different levels of the public administration and the academic and the productive sectors is essential.

## Acknowledgements

We sincerely thank all the people who attended the participatory workshops devoting their time, efforts and reflections towards the future of sustainable farming in the Madrid region. Our thanks also go to the AgroecologiCAM members for their assistance and contribution in the dissemination of the participatory workshops. We want to express our gratitude to all those workers who despite the outbreak of the COVID-19 are keeping the agricultural sector well-functioning. This study received funding from: (1) AgroecologiCAM project funded by the European Union, the Spanish Ministry of Agriculture, Food and the Environment and Madrid Regional Government under the Rural Development Programme (RDP-CM 2014-2020), (2) from the European Union's Horizon 2020 research and innovation programme under grant agreement N◦ 81819, by the project entitled: Co-design of novel contract models for innovative agri-environmental-climate measures and for valorisation of environmental public goods, and from (3) SAVIA-Sowing Alternatives for Agroecological Innovation project funded by a call for R&D projects for young researchers from the Autonomous University of Madrid-Comunidad de Madrid (SI1/PJI/2019-00444).

REFERENCES

Acosta-Naranjo R, Amores-Lemus L, de España-Rigo AS (2019) ¿Agroecología en la España despoblada? Cuaderno de Investigación Urbanística 124:44–58

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agr Ecosyst Environ 74(1-3):19–31, doi:10.1016/S0167-8809(99)00028-6

Altieri MA (2002) Agroecología: principios y estrategias para diseñar sistemas agrarios sustentables. In: Sarandon SJ (ed) Agroecología: el camino hacia una agricultura sustentable. Buenos Aires–La Plata, 49–56

Altieri, MA (2009) Agroecology, small farms, and food sovereignty. Monthly Review 61(3):102, doi:10.14452/MR-061-03-2009-07_8

Altieri MA, Funes-Monzote FR, Petersen P (2012) Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. Agron Sustain Dev 32(1):1–13, doi:10.1007/s13593-011-0065-6

Altieri MA, Nicholls CI, Henao A, Lana, MA (2015) Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev 35(3):869–890, doi:10.1007/s13593-015-0285-2

Anderson C, Pimbert M, Kiss C (2015) Building, defending and strengthening agroecology. A global struggle. ILEIA - Centre for learning on sustainable agriculture, the Netherlands.

Begiristain-Zubillaga M (2018) Comercialización agroecológica: un sistema de indicadores para transitar hacia la soberanía alimentaria. Cuadernos de trabajo 75. Hegoa, Instituto de Estudios sobre Desarrollo y Cooperación Internacional. Universidad del País Vasco, 51 p

Bodiguel L (2014) Quand le droit agro-environnemental tranvennde le droit rural - Réflexions suite à la loi d'Avenir pour l'agriculture, l'alimentation et la forêt de 2014. Revue de Droit Rural, Editions techniques et économiques / LexisNexis

Boletín Oficial de las Cortes Generales (2018) Boletín Oficial de las Cortes Generales: Congreso de los Diputados, XII legislatura. Num. 454:57–58

Borlaug, NE (1971) The green revolution: For bread and peace. B Atom Sci 27(6): 6–48, doi:10.1080/00963402.1971.11455372

Cevallos-Suárez M, Urdaneta-Ortega F, Jaimes E (2019) Desarrollo de sistemas de producción agroecológica: Dimensiones e indicadores para su estudio. Rev Cienc Soc 25(3):172–185

Chavarria DN, Pérez-Brandan C, Serri DL, Meriles JM, Restovich SB, Andriulo AE, Jacquelin L,Vargas-Gil, S (2018) Response of soil microbial communities to agroecological versus conventional systems of extensive agriculture. Agr Ecosyst Environ 264:1–8, doi:10.1016/j.agee.2018.05.008

Claveirole C (2016) La transition agroécologique: défis et enjeux. Paris, les éditions des Journaux officiels

Creswell JW (2008) Educational research: planning, conducting, and evaluating quantitative and qualitative research. Pearson International Edition

Delgado Cabeza M (2010) El sistema agroalimentario globalizado: Imperios alimentarios y degradación social y ecológica. Economía Crítica 10:32–61

del Valle J, Jiménez L, Morán N, Clemente R., Medina Á (2018) La producción agroecológica en la Comunidad de Madrid. Radiografía del presente y una mirada hacia el futuro. Iniciativas Socioambientales Germinando

Dunn OJ (1964) Multiple comparisons using rank sums. Technometrics 6:241–252

European Commission (2015) The European Agricultural Fund for Rural Development: Rural development priorities 2014-2020. Publications Office, doi:10.2762/94317

FAO (2018) Scaling up agroecology initiative – Transforming food and agricultural systems in support of the SDGSs. A proposal prepared for the International Symposium on Agroecology, 3-5 April 2018, 17 p

Francis CA (1986) Multiple cropping systems. New York: Macmillan, 383 p

Franco J, Borras Jr S (2013) Land concentration, land grabbing and people's struggles in Europe. Transnational Institute for European Coordination Via Campesina and Hands off the Land Network

Gallardo-López F, Hernández-Chontal M, Cisneros-Saguilán P, Linares-Gabriel A (2018) Development of the Concept of Agroecology in Europe: A Review. Sustainability 10(4):1210, doi:10.3390/su10041210

García-Llorente M, Astier AC, Clemente-Pereiro R, Hernández-Jiménez V, Palomo S, Redondo-Arandilla M, Martín M, Benito A (2020) Contribución del Grupo Operativo AgroecologiCAM al desarrollo de políticas agroecológicas de la Comunidad de Madrid. In: Simón X, Pérez-Neira D, Copena D (Coord.) VII Congresco de Agroecologíca Políticas alimentarias para a Sustentabilidade, 167–177

García-Llorente M, Pérez-Ramírez I, de la Portilla CS, Haro C, Benito A (2019) Agroecological strategies for reactivating the agrarian sector: The case of Agrolab in Madrid. Sustainability 11(4):1181, doi:10.3390/su11041181

García-Nieto AP, Huland E, Quintas-Soriano C, Iniesta-Arandia I, García-Llorente M, Palomo I, Martín-López B (2019) Evaluating social learning in participatory mapping of ecosystem services. Ecosystems and People 15(1):257–268, doi: 10.1080/26395916.2019.1667875

Germinando (2019) Políticas Públicas y Agroecología en la Comunidad de Madrid. Informe 1: Pensando el PDR desde una Perspectiva Agroecológica, 58 p

Gliessman S (2020) Transforming food and agriculture systems with agroecology. Agr Hum Values 37:547-548.

Gliessman S (2015) Agroecology: A Growing Field. Agroecol Sust Food 39(1):1–2, doi:10.1080/21683565.2014.965869

Harrison S (2013) The problem of sampling in qualitative research. Asian Journal of Management Sciences and Education 2(2):202-210.

Horrigan L, Lawrence R, Walker P (2002) How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environ Health Persp 110(5):445–456, doi:10.1289/ehp.02110445

Karimi A, Brown G, Hockings M (2015) Methods and participatory approaches for identifying social-ecological hotspots. Appl Geogr 63:9–20, doi:10.1016/j.apgeog.2015.06.003

Knapp C N, Fernández-Giménez M, Kachergis E, Rudeen A (2011) Using participatory workshops to integrate state and transition models created with local knowledge and ecological data. Rangeland Ecol Manag 64(2):158-170, doi:10.2307/25835917

Kremen C, Miles A (2012) Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and tradeoffs. Ecol Soc 17(4), doi:10.5751/ES-05035-170440

Kruskal WH, Wallis WA (1952) Use of ranks in one-criterion variance analysis. J Am Stat Assoc 47(260):583–621

Law No. 2014-1170 (2014) La loi d'avenir pour l'agriculture, l'alimentation et la forêt, 2014-1170.

Levidow L, Pimbert M, Vanloqueren G (2014) Agroecological research: Conforming – or transforming the dominant agro-food regime? Agroecol Sust Food 38(10): 1127–1155, doi:10.1080/21683565.2014.951459

López-García D, Pomar-León A, García-Gacía V, Tendero-Acín G, Sampedro Y, Sastre-Morató AN (2018) Contradicciones en los saltos de escala. Procesos participativos y planes de acción para la transición agroecológica en la escala metropolitana. Agroecología 13(1):33–43

Lucas V, Gasselin P (2018) Une agroécologie silencieuse: Ombres et lumières dans le champ professionnel français. 12èmes journées de recherche en sciences sociales INRA-SFER-CIRAD 13–14

Nicholls CI, Altieri MA, Vazquez L (2016) Agroecology: Principles for the Conversion and Redesign of Farming Systems. J Ecosys Ecograph S5:010. doi:10.4172/2157-7625.S5-010

Malézieux E, Crozat Y, Dupraz C, Laurans M, Makowski D, Ozier-Lafontaine H, Rapidel B, de Tourdonnet S, Valantin-Morison, M (2009) Mixing plant species in cropping systems: concepts, tools and models: a review. Agron Sustain Dev 29(1):43–62, doi:10.1051/agro:2007057

Markelova H, Meinzen-Dick R (2009) Collective action for smallholder market access. CAPRI, CGiAR Systemwide Program on Collective Action and Property Rights. Policy Brief 6:1-4

McIntyre BD, Herren HR, Wakhungu J, Watson RT (2009) Agriculture at a crossroads. International assessment of agricultural knowledge, science and technology for development (IAASTD) Global Report. Synthesis Report. Washington DC: Island Press, 590 p

Méndez VE, Bacon CM, Cohen R, Gliessman SR (2015) Agroecology as a transdisciplinary, participatory, and action-oriented approach. Florida: CRC Press, 284 p

Mier M, Cacho TG, Giraldo OF, Aldasoro M, Morales H, Ferguson BG, Rosset P, Khadse A, Campos C (2018) Bringing agroecology to scale: key drivers and emblematic cases, Agroecol Sust Food, 42(6) 637-665, doi:10.1080/21683565.2018.1443313

Migliorini P, Lazzaro M, Bàrberi P, Ciaccia C, Colombo L, Canali S (2017) Convergences, divergence and specificities between Agroecology and Organic Agriculture in Italy. First Agroecology Europe Forum – Session 2 Co-evolution of organic agriculture and agroecology

Opdam P, Nassauer JI, Wang Z, Albert C, Bentrup G, Castella JC, McAlpine C, Liu J, Sheppard S, Swaffield S (2013) Science for action at the local landscape scale. Landscape Ecol 28(8):1439–1445, doi:10.1007/s10980-013-9925-6

Oteros-Rozas E, Ravera F, García-Llorente M (2019) How does agroecology contribute to the transitions towards social-ecological. Sustainability 11(6):1–13, doi: 10.3390/su11164372

Palomo-Campesino S, González J, García-Llorente M (2018) Exploring the connections between agroecological practices and ecosystem services: A systematic literature review. Sustainability 10(12):4339, doi:10.3390/su10124339

PDR Madrid (2017) Spain – Rural Development Programme (Regional), Comunidad de Madrid. The European Agricultural Fund for Rural Development: Europe investigating in rural areas

Pinilla V, Sáez LA (2017) La despoblación rural en España: génesis de un problema y políticas innovadoras. Informes CEDDAR, 2

Poux X, Aubert PM (2018) An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercise, Iddri-AScA

Rosset P, Val V, Pinheiro Barbosa L, McCune N (2019) Agroecology and La Via Campesina II. Peasant agroecology schools and the formation of a sociohistorical and political subject. Agroecology and Sustainable Food Systems 43(7-8):895–914, doi:10.1080/21683565.2019.1617222

Scarborough P, Appleby PN, Mizdrak A, Briggs AD, Travis RC, Bradbury KE, Key TJ (2014). Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. Climatic Change 125(2):179–192, doi:10.1007/s10584-014-1169-1

Silici L (2014) Agroecology. What it is and what it has to offer. In food and agriculture. IIED, Issue Paper

Sourisseau JM, Bélières JF, Marzin J, Salgado P, Maraux F (2019) The drivers of agroecology in sub-Saharan Africa: an illustration from the Malagasy Highlands. In: Côte FX, Poirier-Magona E, Perret S, Roudier P, Bruno R, Thirion MC (eds) The agroecological transition of agricultural systems in the Global South. Versailles: Éditions Quae, 179–197

Spanish Ministry of Territorial Policy and Public Function (2019) Ministerio de Política Territorial y Función Pública Directrices Generales de la Estrategia Nacional frente al Reto Demográfico. Comisionado del Gobierno frente al Reto Demográfico, 100 p

Tilman D (1999) Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. P Natl Acad Sci USA 96(11):5995–6000, doi:10.1073/pnas.96.11.5995

Van der Ploeg JD et al. (2019) The economic potential of agroecology: Empirical evidence from Europe. J Rural Stud 71:46–61, doi:10.1016/j.jrurstud.2019.09.003

Van Vooren L, Reubens B, Ampoorter E, Broekx S, Pardon P, Van Waes C, Verheyen K (2018) Monitoring the impact of hedgerows and grass strips on the performance of multiple ecosystem service indicators. Environ Manage 62(2):241–259, doi:10.1007/s00267-018-1043-4

Wezel A, Bellon S, Doré T, Francis C, Vallod D, David C (2009) Agroecology as a science, a movement and a practice. A review. Agron Sustain Dev 29(4):503–515, doi:10.1051/agro/2009004

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

Wezel A, Goette J, Lagneaux E, Passuello G, Reisman E, Rodier C, Turpin G (2018) Agroecology in Europe: Research, education, collective action networks, and alternative food systems. Sustainablility 10(4):1214, doi: 10.3390/su10041214

Yacamán C, García-Llorente M, Gutiérrez-Briceño I, Fernández M, Benito A (2020) Co-Diseño de soluciones contractuales innovadoras orientadas a potenciar la producción agroecológica y la conservación de bienes públicos ambientales. VIII Congreso Internacional de Agroecología. Universidad de Vigo. 1, 2 y 3 de julio 2020

RESEARCH ARTICLE

# Participatory analysis and action to promote agroecological food systems – methodological insights from a three-country initiative: Nicaragua, Senegal and England

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Received: April 17, 2020
Revised: November 11, 2020
Accepted: November 27, 2020

HIGHLIGHTS

- **Presents a novel and replicable participatory methodology for responding to the complexity and power imbalances of food systems, combining farmer-led participatory action research with complex systems analysis and deliberative processes**
- **Demonstrates how participatory and systemic action research can be applied to produce actionable knowledge and strategies across multiple levels of food systems to contribute to agroecological transitions in varying contexts.**

KEYWORDS **food systems, participatory methods, action research, deliberative process**

## Abstract

Understanding and seeking to change complex systems requires approaches which can adequately respond to complexity and which undermine rather than reinforce dominant power structures. This paper presents and reflects on a participatory methodology developed and applied to transition food systems in England, Nicaragua and Senegal to align better with agroecological principles. The methodology combines participatory research, complex systems mapping and deliberation to understand and respond to the complexities of food systems in an integrated and transdisciplinary way. Where this methodology distinguishes itself from other participatory research approaches is the explicit focus on the multiple dimensions of food systems in an integrative way, which was possible through a deliberative process and by involving various stakeholders, but continuing to privilege (yet also challenge) the voices of marginalised producers. Our experience indicates that the methodology could be used and adapted for various complex topics and contexts in which social change is sought.

## 1 Introduction

This paper presents a methodology for analysing and contributing to the transition of food systems, which are understood to be complex and dynamic (Leach et al., 2010; Ericksen et al., 2010) and which marginalise the voices and experiences of farmers (European Parliament, 2014), one of the most crucial set of actors. The methodology combines farmer-led participatory action research (PAR) with complex systems analysis and deliberative processes in order to adequately respond to the complexity of food systems and address their power imbalances. Its innovation stems from its ability to prioritise the voices of farmers beyond their direct interests. It proposes a strategy to address the sustainability of food systems while ensuring research is transdisciplinary and participatory (Lang et al., 2012; Wiek et al., 2012).

Our project evolved in response to a global food system that is undeniably in a state of crisis and is failing to achieve its principal goal of ensuring food and nutrition security for all people in socially just and ecologically sustainable ways (Ericksen, 2008; Foran et al., 2014). Although agricultural production is enough to feed the world 1.5 times over (Global

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Agriculture Report, 2016; Holt-Gimenez et al., 2012), an estimated 815 million people in the world are undernourished (FAO, 2017). Paradoxically, obesity is increasing in poor and rich countries (Global Nutrition Report, 2016; Ng et al., 2014) due to food systems failing to deliver high quality nutrition, leading to what is known as malconsumption and resulting in adverse dietary health effects (Sage, 2013; Lock et al., 2010). At the core of food production are farmers, who, all over the world are increasingly struggling to survive economically (van der Ploeg, 2008). Many farmers live in poverty, especially those producing on small or medium scale (World Bank, 2014). This is exacerbated by policies that favour agro-industrial production and marginalize small-scale farmers (European Parliament, 2014), excluding them from decision-making processes and leading to negative social outcomes. In addition, industrialised agriculture contributes to increasing environmental damage, loss of biodiversity and eco-system degradation, threatening the viability of the current food production model as a whole (Giraldo and Rosset, 2018; Altieri and Toledo, 2011; Tittonell, 2013). Against this backdrop there are increasing calls for a fundamental change to food systems (UNCTAD, 2013).

As a reaction to these challenges, the concept of agroecology has emerged and evolved as an approach that encompasses the social, ecological and economic dimensions of agri-food systems (Francis et al., 2003: 100; Gliessman, 2007; Wezel, 2009). Agroecology itself is a contested term with various definitions. It has been conceptualised not only as a science and practice at a farm or plot level but also as a social movement across entire food systems (Wezel et al., 2009; Rosset and Martinez-Torres, 2012; Francis et al., 2003). The project on which this paper is based chose to focus on the potential for agroecological food systems to be realised, thus interpreting agroecology in its most transdisciplinary and systems-wide definition rather than focusing only on production. This is based on an understanding of food systems as complex, in which treating issues in isolation (e.g. nutrition at the cost of ecology; livelihoods at the cost of nutrition, etc.) is unlikely to lead to positive changes for the system as a whole (Tendall et al., 2015).

With this food systems understanding of agroecology and the current challenges of complex, unsustainable and unequal food systems, the project Transitions to agroecological food systems: pathways to sustainability, took place in Nicaragua, Senegal and England from 2016 to 2018. The project was initiated and coordinated by a research institute in the UK, the Institute of Development Studies (IDS), and run in partnership with community and farmer-led organisations in each of the three countries. It centred on small-scale farmers who self-identified as practising agroecology, some of whom were involved in agroecological and/or food sovereignty social movements within their contexts. The project team deliberately selected localities in both the Global North and Global South to facilitate an exchange of knowledge and produce a greater understanding of the similar and different challenges faced in spreading agroecological food systems. Yet, of course, knowledge itself is unlikely to lead to change; rather, it needs to be applied, by actors which are relevant, well positioned and empowered to act. Thus, the project also included a component of developing alliances and strategies, rather than simply producing more knowledge.

This article outlines the different phases of the research and demonstrates how a methodology that integrates participatory research and a systemic approach with a deliberative process is suitable for the analysis of complex food systems and their alignment with agroecological principles. The next section expounds the rationale underpinning this methodology and the methodological design. Using examples from the three-country initiative we then illustrate the different phases of the action research and briefly highlight research results and strategy outcomes of the project. The last section closes with a reflection on this methodological framework and how it can support future endeavours to improve participatory research in agroecology and thus the transition to more sustainable food systems.

The positionality of the authors is as follows. The lead author of this paper joined the project halfway through to support in the evaluation of the project process and outcomes. The other two authors were part of the core team of people implementing the project. One of the authors is an ecological food producer in addition to being a researcher. None of the authors are from the UK, though all were living in England at the time of the project.

## 2 Motivation

### Integrating 'participation', 'complex systems thinking' and 'deliberative processes'

Food systems are characterized by their dynamism and complexity as processes interlink on various levels (individual, farm, local, national, global) and are affected by multiple forces (economic, social, cultural, technological and ecological) (Guzmán et al., 2013). Systemic and participatory action research approaches lend themselves to effectively engage with these characteristics and inform the novel methodological design this article describes. Undergirded by a strong deliberative component, the methodological design allows for a discursive and critical analysis and meaning-making process by farmers over time. Illustrated with examples from the three-country initiative this section elaborates on the rationale of the methodology and the anticipated impact, before taking the reader through the methodology and the different phases of the project in section 3.

The methodological framework of this research initiative was developed to a) contribute towards a rebalancing of power relations through approaches that centre on farmers as co-researchers, b) respond to and capture the complexity of food systems, and c) apply an integrated view on the social, economic, ecological and nutritional dimensions relevant for agroecological food systems.

To rebalance power through participation, we purposefully chose an action research approach as it allows to draw on the knowledge and experience that farmers have about their lived realities and local conditions. A participatory research approach, according to Chambers (1995) refers to an "empowering process, which enables local people to do their own analysis, to take command, to gain confidence, and to make their own decisions." Action research (Reason and Bradbury, 2001, 2008) is a participatory, democratic process of iterative cycles of action and reflection that brings together theory and practice, and centres on the development of knowledge (Reason and Bradbury, 2001) that responds to the needs and challenges of people in their everyday lives. Knowledge that is derived under a participatory paradigm has the potential to challenge deeply entrenched power inequalities, as well as the monopoly of conventional research and knowledge production (Gaventa and Cornwall, 2006; Pimbert, 2006). This research has taken a decision to particularly privilege – though also critically challenge – the perspectives of small-scale farmers in the food system who identify as practicing agroecology. This is because small-scale farmers have typically been excluded from decision making about food systems (Pimbert and Wakeford, 2002), yet they have unique understandings of what it is like to produce food and the challenge of working within the existing food systems while maintaining agroecological principles. As agroecological approaches emphasise farmers as protagonists in the research process, as opposed to top-down measures in conventional research, PAR approaches harmonise well with the more political interpretations of agroecology (Guzmán, 2013; Pimbert, 2006). The incorporation of agroecological farmers along with other actors in the food system (as witnesses and as change agents), had the additional benefit of responding to complexity. A growing body of literature acknowledges that because of their multi-dimensional, multi-levelled, dynamic and uncertain nature, research about complex issues require a wide range of knowledge to be incorporated from across different disciplines and actors, but with facilitation of 'scaffolding' to support constructive dialogue and the emergence of new perspectives (Burns 2014, Burns and Worsley, 2015, Lang et al., 2012, Jordan et al., 2013).

To further respond to complexity, we chose to use an approach based on participatory systemic inquiry (Burns, 2012, Harvey et al., 2012). Participatory systemic inquiry is an approach which can be incorporated into action research, and which emphasises "developing processes and learning architectures that can effectively engage with complex systems dynamics" to support systemic change (Burns, 2014: 3). Specifically, the complex nature of food systems means that conventional research approaches which look at single issues (production, distribution, marketing, consumption) in isolation are inadequate (Thompson and Scoones, 2009; Jordan et al., 2013). Instead, our process included a focus on the ecological, economic, social and nutritional aspects of food systems throughout. This focus brought the inquiry out beyond the direct interests of food producers and into wider societal and ecological considerations.

Two complexity-congruent methods which we used in this research were complex systems mapping and deliberative processes. Systems mapping helped to visually account for the non-linear interactions of diverse actors and issues across scales and levels in food systems. Rather than an end in itself, systems mapping in this project was used as a tool to facilitate discussion and analysis, as described in the next section. It was also used for setting research questions, which were deliberately not formulated at the outset by the research team, in order to both challenge conventional research power dynamics and respond to the uncertainty and disagreement about the problem which characterises complex issues.

Deliberation as a form of discursive participation (Carpini et al., 2004) was incorporated to support the action-reflection cycle of PAR, and because the nature of this research requires a process that facilitates critical and dialogic analysis of the issues in question and the provided evidence. A deliberative process can bring in different perspectives of various stakeholders of the food system to provide a better understanding of its complexity; it enables participants to make sense of the research findings as well as challenge them; it enables participants to contextualise and appropriate research findings within their realities; it provides an arena to discuss different strategies for change; it can build solidarity between participants and underpin decisions they have reached collaboratively with legitimacy (Kemmis and McTaggart, 2006). A deliberative process in which different stakeholders come together to debate, reflect on and challenge each other's experiences and perspectives without having to find consensus is a way to address complexity and avoid potential groupthink, thus addressing a common downfall of participatory research (Cooke, 2001; Wakeford et al., 2008). Considering the values of participation and agroecology in terms of constituting bottom-up approaches and being context specific (Guzmán, 2013; Pimbert, 2006), and also considering the wide range of interpretations of agroecology (Bellwood-Howard and Ripoll, 2020), it was deemed important to ground the project in what the farmers themselves understood to be agroecological food systems. We chose to present four different dimensions for participants to reflect on: social, ecological, economic and nutritional, with a view to ensuring that the participants went beyond their own interests and concerns as food producers to consider the wider aspects of food systems beyond production.

In sum, incorporating these conceptual considerations our methodological design led to an approach which included different phases of participatory systems mapping, research, deliberation, alliance and strategy building and learning across countries. These phases are described in a practical way in the following sections, with a view to them being adapted and replicated in future participatory research on agroecology.

## 3 Methodology

The research process was designed by the UK research team and co-led by farmers who created the content, allowing them to inquire themselves into their situation as agroecological growers and the manifold factors that affect them. While the farmers did not initiate the project, they were at the centre of the inquiry, with power to make decisions about the content and direction and the ability to shape the process itself. The participatory research design enabled farmers to set the research agenda, analyse the findings and negotiate their meanings and implications. Involving farmers actively in the research and basing it on their lived experiences ensured the relevance of the project to them personally and led to a sense of ownership over the process and continued momentum after the process ended.

The methodological design was structured in the below mentioned phases (Figure 1) for all three countries, whereby the implementation of individual phases could vary slightly across locations.

**Phase 0**: Selecting participants and creating a safe space

Initial and ongoing considerations of how to select participants for the farmer panel and ensure that there is an ability for people to challenge one another and themselves.

**Phase 1:** Participatory systems mapping and identification of research questions

Reflecting on food systems and creating messy maps and distilled maps enabled farmers to visualise their actual food systems and identify causal relations and patterns. From there they determined 4-6 research questions.

**Phase 2**: Research

The identified research questions led to micro-research projects undertaken by local partner organisations.

**Phase 3**: Deliberation

The evidence resulting from the research was presented back to the farmers' panels and supplemented by invited key informants and experts pertaining to the different topics. In a deliberative process the farmers reflected on and challenged the findings and their own ideas, as well as identified potential allies who would be in a position to support them in their strategising.

**Phase 4**: Change agents workshop

The identified allies were invited to a 'change agents' workshop, where farmers could present their findings and jointly develop feasible strategies.

**Phase 5**: Global summit in Nicaragua

The project activities culminated in a summit in Nicaragua where participants of all three countries (Nicaragua, Senegal and UK) came together. This served as a platform for farmers to share their experience and ideas, to reflect on similarities, differences and correlations, to develop action points for their respective countries and to build international networks to promote agroecology.

FIGURE 1
The research desgin

## 4 Process description and exemplary results

### Phase 0: Selecting participants and creating a safe space

**Selecting participants:** Who to invite as participants is a first crucial step (Bergold and Thomas, 2012; Wakeford et al., 2008). The consideration of who to engage depends on the nature of the project and who can contribute the knowledge required for what wants is to be achieved. The participant selection did not aim to get a sample representative of the population or even of agroecological farmers. Rather, the primary consideration was to create a panel with a combination of people which could generate insights about the challenges of producing agroecologically within existing food systems but more specifically about how to identify leverage points that are suitable to induce systems change.

Burns (2012, 2014) pointed out that there are trade-offs between Participatory Action Research (PAR) and Systemic Action Research (SAR) in terms of the homogeneity of the participant panel and the diversity of worldviews that they yield. In order to achieve a multiple-perspectives view of systems, SAR involves a variety of people in the research process that can have completely different interests, and that join and leave as necessary (Burns, 2014: 9). PAR however, is centred on a community or fixed group of participants that carry the entire research process, part of which is to identify and counteract unequal power relations. In a pure SAR approach for example farmers might lose their weight and centrality in the project if stakeholders with different interests were part of the process. While a multi-stakeholder panel ensures a diversity of worldviews, it has the disadvantage of risking co-option by more powerful actors and yielding knowledge that is not specifically relevant or action-oriented. On the contrary, in PAR the emphasis is clearly on amplifying the voice of a specific marginalized group, which means that less emphasis is given to the concerns of other stakeholders and that other perspectives would be less represented in the research. A group of people with similar goals, problems and strategic interests leading action research will ensure that the knowledge generated is relevant for their lives and generates practical action to pursue. The disadvantage will be that other worldviews from other stakeholders will not be present in the panel. There is no 'right' make-up of the panel, but rather a need to acknowledge and redress the drawbacks (e.g. bringing other voices into the analysis). In our case, we tended towards the interest group-based approach, using the deliberation process to bring in the perspectives from other actors in the food system (consumers, traders, retailers and so on). The methodology featured in this paper seeks to create a systemic PAR approach, that offers the potential to use elements of both approaches and adjust the weight that is given to either one according to the scope and context of the research.

The idea was that farmers, who are at the centre of food production, come together, bring to the fore and consolidate their first-hand experiences and knowledge. The farmers were selected purposefully for their previous engagement – or interest – in agroecological or sustainable agriculture, with many (but not all) belonging to organisations that were linked to agroecological or food sovereignty social movements. It was anticipated that this particular positioning could yield the tensions and contradictions between farmers' immediate economic survival (which entails working within the existing system) and their other goals and aspirations such as regenerating their land, building communities and equitably nourishing populations, which may require significant changes to the systems on which they currently depend. Further, involving those who are already active in the agroecological movement and demonstrating an interest in the matter had the benefit of high engagement throughout the project and beyond.

Variety and balance are important criteria to ensure versatility and inclusion of less represented or marginalized groups as well as a variety of perspectives. In our examples the farmers' panels, also called 'juries', consisted of 10 – 13 members of a mix of genders and age groups, representing different types of production and different levels of involvement with farmers' or civil society organisations. Calling the farmers' panels a 'jury' in Nicaragua and Senegal was a symbolic way of declaring the farmers' knowledge as priority and was met with affirmative positive feedback from the farmers. In the English context, the term 'panel' resonated well with the farmers and for some, gave a sense of prestige to their participation. The geographical scope varied depend on the country. In the UK, discussions were mostly relevant to England, in Nicaragua, to the Central and Pacific regions, and in Senegal, to the region of Casamance.

In practice, many of the eligible and interested participants for this project held a representative or leadership position within their community or organisation. This presented both strengths and risks. One of the strengths of including such individuals with leadership roles is that they brought a wealth of issue-specific knowledge about the promotion of agroecology, having engaged in it for some time. They also had strong networks through which knowledge from the project could be disseminated and acted upon.

The risk was that of re-enforcing existing power relations through privileging some voices at the expense of others during the process (Cooke and Kothari 2001). Thus, there is a trade-off that emerges when constituting the panel. There is no 'right' combination of leaders (who in our project were themselves farmers) and 'lay' people, rather the structure of the participatory process needs to reinforce and give space to those voices that are at risk of being diminished. Further, a number of facilitation measures were put into place in order to avoid and/or counteract power imbalances in real time during workshops and through reflection and feedback throughout the project. The following section describes ways in which this was undertaken.

**Facilitation, power and creating a safe space:** "Reflexivity is a hallmark of excellent qualitative research and it entails the ability and willingness of researchers to acknowledge and take account of the many ways they themselves influence research findings and thus what comes to be accepted as knowledge." (Sandelowski and Barosso 2002: 222)

Facilitation is not neutral (Kemmis and McTaggart, 2005: 285 f.; Burns, 2015). Like any other person, the facilitator is subject to her or his ontological and epistemological position and therefore not free of values, beliefs and vested interests. These can influence the direction in which she or he guides the process, analyses data and draws conclusions. Whether intended or not, a facilitator exercises power: facilitators have the power to include or exclude perspectives, open up communicative and safe spaces or shut them down, influence relationship dynamics and even manipulate the process (Burns, 2015: 157; Chambers, 1997: 155).

In this project, workshops were facilitated by an IDS researcher and co-facilitated by a local researcher embedded in the partner organisation. The biases and positionalities of the research team were mitigated by the use of participatory exercises which entailed metaphorically 'handing over the stick' to participants (Chambers, 1997: 157). The project drew on exercises espoused by Chambers (2012) and Kaner et al. (2014) which encouraged inclusivity and empowerment of participants.

Facilitators also endeavoured to be reflexive about their own positionality and the power they themselves exercise, intentionally or not (Muhammad et al., 2015; Burns, 2015: 157 f). Reflexivity of positionality was supported by co-facilitation and by cross-country facilitator debriefings after each major workshop.

Another crucial element for mitigating power inequalities was the creation of a safe space (Bergold and Thomas, 2012; Gayá-Wicks and Reason, 2009). In the panels, farmers of different types of production, most of whom did not know each other, came together, not being sure what to expect or what exactly was expected from them. Participants from all three countries emphasised the importance of establishing ground rules at the beginning, to create a space where people's interpersonal needs of inclusion and intimacy were met, so that they could feel free to speak their minds. Creating and maintaining a safe communication space is crucial for achieving a high level of participation, and a way to address power relations, as spaces "are infused with power relations, affecting who enters them, who speaks with what knowledge and voice, and who benefits. This is particularly apparent, for example, when both professional knowledge and peoples' experiential knowledge are brought together in the same space and discussed." (Pimbert, 2006: 19)

A safe communicative space was created by establishing 'ways of working' together in the first workshops by discussing ground rules such as the types of confidentiality to be had, active listening, empathy, giving people space to voice their opinions and, crucially for the deliberative aspect of the project, not needing to agree on everything.

In England, the 'ways of working' were revisited at the beginning of each workshop, even though they had been discussed a number of times. Participants themselves would present to the group different principles for working together that felt important for them. The group would then be able to add to or discuss any additional details.

The exercise was less repetitive than the researchers had anticipated, and as workshops progressed, exemplified the ownership that participants felt of the process. New principles were added, and existing ones were adjusted or clarified with nearly every iteration. At the beginning of the final workshop, for example, one participant had new reflections and disagreed about the importance of one of the ways of working which had previously governed the group dynamic. He questioned whether it was necessary to be stipulating 'safe expression', given that there was no threat of physical violence within the group. Rather than the facilitators jumping in to explain what 'safety' meant in this context, a number of participants expressed their own previous life experiences of not feeling able to speak up in group settings because of gender and age dynamics, with other participants adding details for clarification. The resolution of this issue by the group – rather than by the facilitator – is one small example of the ways in which the process enabled participants to set boundaries and respond to their needs for expression.

## Phase 1: Participatory food systems mapping and definition of research questions

"I loved the alchemy of the chaos - in the beginning it seemed chaotic, but then things started to emerge." (Farmer, England)

Complex systems are very difficult to grasp due to their non-linear interactions and dynamism (Leach et al., 2010; Ericksen et al., 2010; Burns, 2015; Foran et al., 2014). Visualising a system through participatory mapping can enable participants to see the 'bigger picture' and identify correlations, patterns, causalities and leverage points (Burns, 2012; Burns, 2015; Burns and Worsley, 2015) that will serve as a foundation for building strategies for systemic change. In this methodological design the mapping process served five purposes:

- Facilitating reflection
- Generating new insights and perspectives
- Creating systems (or 'messy') map(s) of the food system
- Deriving distilled maps of specific issues within the food system
- Determining researchable questions

The systems maps, to which we also refer as messy maps (Burns, 2015) due to their initial chaotic appearance, served as starting points of this inquiry as they formed the basis for discussion, reflection and the generation of new insights into food systems. The mapping process was preceded by a session in which participants reflected on their own lived experiences of trying to work agroecologically, and what they understood agroecology to be when considered considering its relevance to the food system as a whole, exploring the four dimensions of food systems (social, ecological, nutritional, economic) as guiding points. During this process, they identified the factors which had impacted their reality. It was important that people focused on their own lives, so that the mapping was grounded in the participants' actual

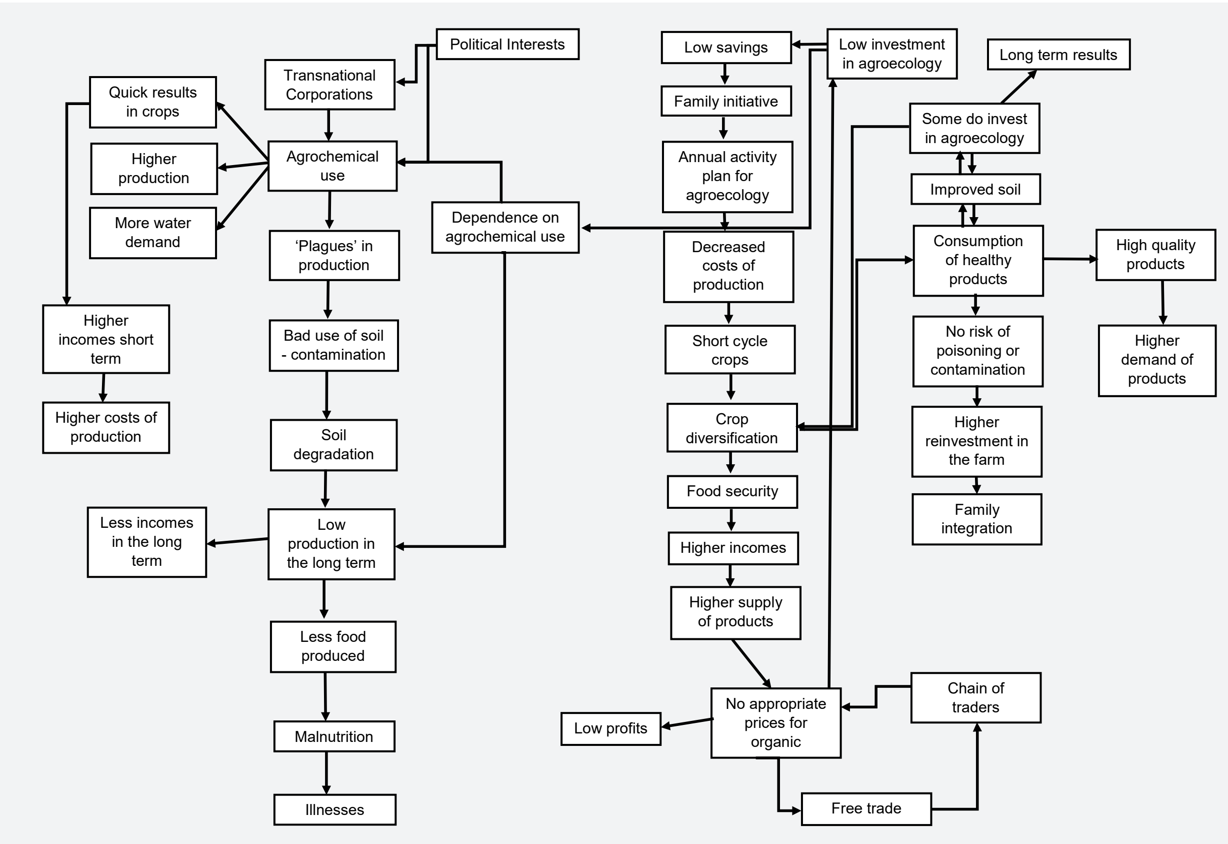


FIGURE 2

Distilled map 'Economic profitability and environmental impact in the medium and long term' by Nicaraguan farmers experiences, rather than perceptions of others, which can be biased or limited.

Rather than an analytical tool, these categories of sustainability were a heuristic device to reflect on what agroecology meant to participants, to remind facilitators and participants of the multidimensional nature of food systems i.e. they span beyond production into distribution and consumption and beyond agriculture to other domains such as social welfare, economic policy, and so on. It also served to highlight how factors that may be positive in one dimension may undermine sustainability in others. For instance, organic edible flower production (i.e. a niche product) may enable farmers to achieve economic and ecological sustainability but is unlikely to contribute to nutritional sustainability. These categories can be expanded or modified according to the needs of the panel, for example including categories like health more broadly, animal welfare, biodiversity, etc.

Upon completion of and reflection on the messy maps, participants identified common themes, or core issues that seemed to be integral to the issue of transitioning food systems. In each country, the participants identified 3-6 salient topics. These were explored further through, so-called distilled maps (Burns, 2015: 77 f) (*Figure 2*). Distilled maps allowed the deliberative panels to zoom in on particular issues and articulate and perceive more clearly how factors relate to each other and what dynamics they cause. From reflecting on the distilled maps, the groups identified issues that needed to be explored further. These then became the research questions for the group.

**What else do we need to know? Determining the research questions:** The distilled maps served as the basis for deriving the research questions. Through the process of mapping and deliberating farmers identified and collectively agreed four to six areas of research that had the potential to yield relevant insights and understanding of how to move towards more sustainable food systems. Collaboratively participants and the researcher-facilitators turned the various lines of research into researchable questions and sub-questions which led to what we called 'micro-research' projects, small research projects that could be solved through a few days of inquiry.

By participants setting the research agenda the project sought to overcome a significant and often overlooked source of bias in research: the research questions that are asked and those not asked (Ioannidis, 2005; Greenhalgh and Russell, 2009). This bias is strongest when research questions are formulated by 'outsiders' and not the people actually involved with and directly affected by the issue. *Table 1* provides an overview of the research themes and questions developed through the project.

## Phase 2: Conducting collaborative research

The type of research that was employed for this second phase of the project was farmer-led collaborative research. The farmer panels posed the research questions above and commissioned the micro-research projects to their respective farmer organisations. These farmer organisations then carried out the research as a result of the interaction of in-house technical officers, and research consultants linked to the agroecology movement in the case of England and Nicaragua. In the case of Senegal, the collaboration occurred with agrarian researchers from the Senegalese Institute for Agricultural Research (ISRA). The role of the Institute of Development Studies was to support the research processes and give guidance to collaborating partners in terms of approaches, methodologies and analysis. This approach aimed to enable grassroots organisations to develop their capabilities to engage in research processes. There are, however, trade-offs between choosing farmer-led collaborative research and strictly defined action-research, in which farmers conduct the research themselves. The further removed from the farmers the research is, the less likely it will yield knowledge relevant to them. On the other hand, areas of interest may fall outside the usual area of experience of farmers e.g. trade agreements and policies around subsidies, and thus research conducted by a trained researcher can be a

**TABLE 1**
Research themes or questions

| Country | Research themes |
|---|---|
| Nicaragua | • Markets and their politics<br>• Management of water and forest resources<br>• Comparison of agroecological and conventional approaches<br>• Land access and land tenure<br>• Youth in agriculture<br>• Public awareness about agroecological products, health and nutrition |
| Senegal | • What is the existing knowledge of agroecology within our communities?<br>• How can existing diversification be best utilised to support improved nutrition?<br>• How can we increase access to agroecological production inputs?<br>• What are the capacities of existing agroecology organisations to promote agroecology? |
| England | • What can promote increased access to land for agroecological farmers?<br>• How can we ensure the contribution of agroecological farmers is valued appropriately?<br>• How do and to what extent do subsidies affect the cost of food?<br>• What has led to the development of sustainable local food strategies, and what have these entailed? |

useful contribution to the process. There is potential to combine both approaches, research conducted by farmers and collaborative research with relevant researchers, aiming to maintain the balance between action-relevance or results and adequate scope of expertise.

Most of the research conducted was a result of secondary data analysis and key stakeholder interviews and focus groups. Only in the case of Senegal was primary research conducted. For the purpose of food system analysis for action, a significant amount of information was available (academic and grey literature, key informants interviews, etc.): the role of the researchers was to 'ground' and translate that research for the requirements of the farmer panels, rather than conducting new research.

## Phase 3: Deliberation

Following the completion of research projects, a series of deliberations were held in each of the respective localities. First, panel or jury members reminded themselves of the research questions and were presented with the research findings. This was through a combination of written summaries and oral presentations. Then, up to four witnesses presented their views about the research topic to the farmers to spark a discussion. Witnesses were key informants (researchers, activists or practitioners) whose expertise and insights would spark productive debate. Presenters were urged to use a range of techniques for sharing their opinions, in order to ensure their content was accessible to all participants. After presenting, they left the room, and the farmers reflected individually and discussed in pairs. They then individually identified what questions they had for the witness. The witness was then brought back into the room for questioning and comments by the farmer panels. Having participants reflect and identify their questions individually and in pairs helped to prevent quicker thinkers or more confident participants from dominating the group deliberations. The talking playing field was also levelled through some use of 'stacking,' a facilitation tool used to establish turns and enable everyone to speak, along with flexibility to allow for dynamic interactions (Kaner et al., 2014). After questions and comments were fielded, the floor was open to general discussion and deliberation, with witnesses and farmers interacting as equals in the discussions.

The deliberations did not necessarily need to lead to conclusions or to consensus. While consensus was reached on many occasions, at times what was most important was the surfacing of disagreements and tensions that were otherwise unrecognised. Given the plurality of the agroecological movement, explicitly recognising these differences was arguably as valuable as finding agreements and clarity. In the spirit of action research, it is hoped that these areas of ambiguity might be further explored through future iterations of questioning, inquiring and reflecting, individually or collectively.

Following these discussions, the witnesses left the room and farmers revisited the distilled maps, reflecting on what was missing or what needed editing in their maps, as well as what was needed as a next step to change or overcome a particular challenge. Another round of reflection and deliberation ensued to identify potential strategies and next steps. This process focused on what might lead to 'tipping points' or changes in key dynamics or path dependencies of the system (Burns and Worsley, 2015). Strategies were then ranked in terms of feasibility, impact and passion for action, and a short-list of strategies was collectively decided. For each strategy, change agents were identified for outreach and invited to a 'change agent' workshop (see Phase 4).

Some highlights of the research results- including insights from the deliberative process

It is outside the scope of this article to describe in full the research results of 12 micro-research projects conducted by local researchers and the added insights provided by the deliberative workshops, as our main goal here is to showcase the methodology. That said, it is useful to offer some highlights in terms of content to understand the relevance of the activities described.

In Nicaragua, the research highlighted the lack of price differentiation for agroecological or even organic products, an exposure to fluctuating and low-return global markets through free-trade agreements and a policy bias toward large-scale plantation farmers. Positive experiences were collected of farmers' market promotion and the benefits of producer and buyer cooperatives. A similar bias in favour of plantation farming occurred in terms of the uneven implementation of an otherwise progressive environmental legislation. In terms of agroecological production, the economic environment pushed small-scale farmers to short-term risk mitigation for survival that side-lined other priorities, such as the long-term soil health and fertility. This lack of profitability, coupled with patriarchal decision-making dynamics in the household, makes agriculture unappealing to young people. Land is progressively being concentrated in the hands of wealthy producers, shifting towards cattle and monoculture production of cane, palm and other cash crops, whilst landlessness increases. Consumers play a role in the lack of price differentiation of agroecological production, as they are less aware of the different benefits of food produced agroecologically.

In Senegal, the primary research showed diverse understandings and practices of agroecology in Casamance, and the coexistence of conventional and agroecological techniques. It also identified preferred methods of communication of agroecological techniques, not only through engaging with farmers (radio, traditional oral communication, demonstration plots, etc.), but also encouraging system-wide alliances beyond production, such as engaging with leadership of farmer groups, and owners of canteens and restaurants, so as to encourage them to source agroecological produce. Another micro-project established the linkages between agroecological produce, dietary diversity and improved nutritional outcomes. Lastly, an analysis on the availability and affordability of inputs showed the impact of subsidies on farmers' preference for agrochemical use, the unavailability of native seeds and the potential of community organisation for agroecological input provision, e.g. seed banks.

In England, the research focused on the market and subsidy systems that have enabled extreme land concentration, leaving agroecological new entrants struggling to access land. Important drivers identified included financial investments in land, and planning policies. Potential avenues to enhance access were identified, from promoting tenancy opportunities, to the implementation of a statutory land registry and reforming planning policy. In relation to markets, the research evaluated critically and comparatively the different schemes to incorporate other forms of value into the cost of food such as triple cost accounting (environmental, social and economic costs), or true cost accounting and how they could be helpful in the promotion of agroecology. The literature review on subsidies highlighted the contradictions in the subsidy regime and the bias towards grains and food manufacturing and showed the myriad of factors that drive prices and the difficulty of attribution. Lastly, the research identified the factors that contributed to the development of local sustainable food strategies: mobilisation and commitment of different public (local councils, NHS bodies, educational institutions and housing associations), private (local farmers, traders, retailers and caterers) and coordinating local associations, NGOs or community interest companies.

## Phase 4: Strategy and Alliance building

A defining characteristic of Action Research is its orientation towards transformational action, not only to understand social phenomena, but, unlike conventional social science, to generate knowledge in order to effect a desired change (Bradbury, 2010). Through deliberation and several cycles of action and reflection, the previous phases of the project facilitated the formation of a body of new and refined knowledge that the farmers put into action as they identified key stakeholders ('change agents') in the food system who could be potential 'allies' in pursuing strategies for moving towards more sustainable food systems. Change agents, which are indispensable actors in any process where change is pursued, can be individuals or organisations (Rothwell and Sullivan, 2005) which have the capacity and position to induce change and to effectively interact with the gatekeepers responsible for maintaining the actual structures (Wielinga et al., 2008; Argyris and Schön, 1996). These change agents were invited as participants to the 'change agents' workshop'. The 'change agents workshop' was a significant step in the project in which participants, based on their new understandings and self-assurance (Bergold and Thomas, 2012: 13), assumed agency and carried action beyond their group to involve stakeholders on multiple levels. Linking the research to the broader debate serves as a catalyst for inducing desired change.

**The 'change agents' workshop':** Between 10 to 20 change agents or 'allies' per country were invited to partake in 2-day 'change agent' workshops. As opposed to conventional stakeholder engagement, the identification and selection of change agents was undertaken by the farmer panels following on from the preceding phases of collaborate analysis and deliberation. They ranged from representatives of agricultural ministries, ethical bankers, nutritionists, planning commissioners, radio stations (in Nicaragua) and traditional oral narrators (in Senegal), only to name a few. The objective was to forge alliances and build actionable strategies with key actors who were in a position to influence driving factors in the favour of more sustainable food systems.

In the sessions of these workshops, the farmers presented to the enlarged group of farmers and change agents on the various topics which had emerged as priorities in the deliberative workshop, explaining the problems as well as the findings from the research and the conclusions from the deliberations. Following this, a facilitated deliberation was opened for the entire farmers' panels and the invited change agents, to include everybody's contributions. At the end of each day farmers and change agents agreed on concrete action points, the responsible person or organisation to carry it out and a realistic time frame to complete them.

In all three countries, the change agents' events denoted a constructive phase in which farmers harnessed their newly gained understandings and self-confidence to step out of their circle and engage key actors of the wider food system. The positionality of the farmers in the centre of the project – presenting their research and deliberation findings and their draft strategies – possibly gave them additional credibility with the invited change agents. Local researchers and participants involved, more used to conventional research, were surprised on the shifts of power-relations away from top-down, 'expert' led processes. For example, a researcher and community organiser in Nicaragua reported: "Until now I have not seen in my work in this country a process in which campesinos (peasants or farmers) themselves do the discussions and analysis of their food systems."

This direct collaboration with change agents has laid the ground for expanding and intensifying the farmers' networks and building actionable strategies to transition to more sustainable food systems.

## Phase 5 Global summit

The action research was not designed to be comparable across countries, but rather to adapt to the context-specific needs of each locality. However, a global summit was organised to gather some lessons that could be learned across countries and to promote exchange of experiences and ideas between the deliberative panels. Through the 3-day participatory workshop, farmers from each country presented key insights from the participatory analysis of their country's food systems and their strategies and alliances for action. Participants then compared between the different country experiences. The key issues which were common to all three countries -although unfolding in different ways due to different ecologies and political economies- were access to land, markets and trade, communication and awareness-raising, and forming alliances. An insight of significant impact for farmers across the three countries was the difficulty of access to land in England, particularly the inability for many farmers to live on their farms. The struggles faced by farmers in England appeared to turn on its head the typical narrative of 'developed' and 'developing' countries.

### Outcomes

Whilst this project could not possibly redress the lack of sustainability and of food systems in Nicaragua, Senegal and England, it did generate some localised impact, both in terms of kick-starting initiatives that promoted agroecology and highlighting the avenues for change, as well as countering top-down power relations in food system research and the position of farmers in the production of knowledge. Highlights of strategies are presented here, though these have not yet been evaluated for their ability to effect systemic change, in part due to the timescale of the initiatives. Perhaps most importantly has been the sense of empowerment reported by the farmer participants. One farmer in Senegal, for example, stated, "It was the first time I experienced a project like this, [a project] that changed the community."

One of several examples of actions from Senegal is the cooperation with a nutritionist, a cookery school and designated local restaurants. With them the farmers worked out a plan where the nutritionist would teach farmers, restaurant owners and youth that attend a cookery school the nutritional and taste value of agroecological food. In the cookery school students would learn to prepare nutritious meals from agroecological produce and cater to designated restaurants. This has the potential to reach a large number of people and the entire process is embedded in awareness-raising as a method to promote agroecology effectively. A new network of agroecological farmers across the Casamance region of Senegal was created, to share experiences in agroecological production.

In England, farmers were able to form and strengthen alliances with key stakeholders for policy changes. Among them two ethical investment banks that provide funding for sustainable agriculture and representatives of planning bodies that are instrumental in the interpretation of planning policy and its revision. Farmers were also well-positioned to feed into agricultural policy making opportunities which arose from Brexit, and fed into government consultations, met with parliamentary members and developed and strengthened policy and advocacy materials.

In Nicaragua, farmers participated in the First National Agroecological Forum that was hosted by UNAG , the Nicaraguan National Union of Farmers, to promote agroecology in Nicaragua. In this forum, which also included a strategy-building-section, the farmers shared their experiences and research findings with key stakeholders in agroecology and government. Artists contributed to help spread the message, and farmers had the opportunity to share their experiences on radio and TV. The research pointed to a high potential for systemic change when initiated at the local and municipal level, and members from the farmers jury have been speaking to community radios to communicate the key messages emerging from the action research.

## 4 Conclusion

The project 'Transitions to agroecological food systems' applied a methodological approach that combines systemic and PAR supported by a strong deliberative component. Especially tailored to analyse food systems and contribute to systemic change, this methodology additionally draws on values of agroecology and food sovereignty: enabling participatory processes that emphasise context-specificity and actively involve those in the research who are directly concerned by an issue, and not leaving it to outside experts. This methodology draws from the commitment of both participatory and agroecological approaches to realising just futures and reshaping asymmetric power relations (Méndez et al., 2013) to enable systemic change. Where this methodology distinguishes itself from other participatory research approaches is the explicit focus on the multiple dimensions of food systems in an integrative way. This was achieved through a deliberative process and by involving various stakeholders across multiple levels of the food system for each of the three countries..

The expectation of deploying this methodological approach was that it would facilitate the emergence of new knowledge, enabling farmers to adjust their views, develop new perspectives and, it follows, new strategies for change (Gaventa and Cornwall, 2006). Farmers gave account of how being involved in the research process, being able to build on their own knowledge and creating the content themselves based on their lived realities was not only satisfying but increased the relevance of the research outcomes for their own lives. They also gained a sense of ownership over the process. Farmers' knowledge was recognised and valued, yet their perspectives were also challenged through engagements with other farmers, witnesses, change agents and research findings. This facilitated a process in which participants could develop new ideas and new ways of framings both problems and solutions. In Senegal, for example, farmers realised that agroecological knowledge and practices are part of their cultural heritage – even though some farmers did not know the term agroecology before – and determined that agroecology represents a strategy to oppose neo-colonialism .

The participatory methodology facilitated an empowering process that enabled farmers to feel more confident to assume agency beyond their immediate circle and participate in new spaces: for example, when they identified and involved key stakeholders for the 'change agents workshop,' or when Nicaraguan farmers presented their cause on national radio and in the First National Forum of Agroecology. This resulted in the expansion of their networks within the agroecological movement, and with other stakeholders in the food system. The use of participatory and inclusive methods played a valuable role in the capacity building of farmers and local research partners. Farmers gave account of how through the participatory workshops they had appropriated the way of organising and structuring their thoughts and how to express them; skills they started to use in other areas of their lives as well. Through engaging and building the skills and capacities of local facilitators and researchers it is hoped that capabilities will remain with the communities and benefit them beyond the project duration.

The methodological framework and description of the process presented in this paper demonstrates how different members of the action research family – participatory and systemic action research - can be creatively integrated to meet context-specific requirements and produce relevant and actionable knowledge and strategies. While rigorous evaluation of the efficacy of strategies actioned has not taken place, evidence about the empowerment and capacity development effects of the project suggest that the methodology is relevant and effective for research efforts endeavouring to contribute to transitions to agroecological food systems. It also appears to be adaptable for a multitude of topics that are complex and require systemic change through the involvement of various stakeholders across the system, including those whose voices are typically marginalised.

## REFERENCES


Altieri MA (1995) Agroecology: The Science of Sustainable Agriculture, Boulder CO: Westview Press

Argyris C, Schön D (1996) Organizational Learning II: Theory, Method, and Practice, Reading, MA: Addison–Wesley

Bellwood-Howard I, Ripoll S (2020) Divergent understandings of agroecology in the era of the African Green Revolution. Outlook Agr 2020; 49(2):103–110, doi:10.1177%2F0030727020930353

Bergold J, Thomas S (2012) Participatory Research Methods: A Methodological Approach in Motion. Forum: Qual Soc Res 13(1), Art. 30, doi:10.17169/fas-13.1.1801

Bradbury Huang H (2010) What is good Action Research? Action Res 8(1):93–109, doi:10.1177/1476750310362435

Burns D (2012) Participatory Systemic Inquiry. IDS Bulletin Special Issue 'Action Research for Development and Social Change', 43(3):88–100, doi:10.1111/j.1759-5436.2012.00325.x

Harvey B, Burns D, Oswald K (2012) Linking Community, Radio, and Action Research on Climate Change: Reflections on a Systemic Approach. IDS Bulletin Special Issue 'Action Research for Development and Social Change', 43(3):101–117, doi:10.1111/j.1759-5436.2012.00326.x

Burns D (2014) Systemic action research: Changing system dynamics to support sustainable change. Action Res 12(1):3–18, doi:10.1177/1476750313513910

Burns D, Worsley S (2015) Navigating complexity in international development: Facilitating sustainable change at scale. Rugby, UK: Practical Action Publishing

Carpini M, Cook F, Jacobs L (2004) Public Deliberation, Discursive Participation, and Citizen Engagement: A Review of the Empirical Literature. Annu Rev Polit Sci 7:315–344

Chambers R (1995) Paradigm shifts and the practice of participatory research and development. In: Nelson N, Wright S (eds) Power and Participatory Development: Theory and Practice, London: Intermediate Technology Publications, 30–42

Chambers R (1997) Whose Reality Counts? Putting the First Last. Rugby, UK: Practical Action Publishing.

Chambers R (2012) Participatory workshops: a sourcebook of 21 sets of ideas and activities. Routledge

Cooke B, Kothari U (2001) Participation: The New Tyranny?, London: Zed Books

Cooke B (2001) The Social Psychological Limits of Participation? In: Cooke B, Kothari U (eds) Participation: The New Tyranny? London: Zed Books, 102–121

Ericksen PJ (2008) Conceptualizing food systems for global environmental change research. Global Environ Chang 18(1):234–245, doi:10.1016/j.gloenvcha.2007.09.002

Ericksen P, Stewart B, Dixon J, Barling D, Loring P, Andreson M (2010) The value of a food system approach. In: Ingram J, Ericksen P, Liverman D (eds) Food Security and Global Environmental Change. London: Earthscan

European Parliament (2014) Family Farming in Europe: Challenges and Prospects [online] Directorate General for Internal policies. European Parliament: Brussels. IP/B/AGRI/CEI/2011-097/E027SC2, retrieved from <http://www.europarl.europa.eu/RegData/etudes/note/join/2014/529047/IPOL-AGRI_NT(2014)529047_EN.pdf> [at 16 Mar 2020].

FAO (2017) FAO, IFAD, UNICEF, WFP and WHO: The State of Food Security and Nutrition in the World 2017, Building resilience for peace and food security. Rome: FAO.

Foran T, Butler JR, Williams LJ, Wanjura WJ, Hall A, Carter L, Carberry PS (2014) Taking complexity in food systems seriously: an interdisciplinary analysis. World Dev 61:85–101, doi:10.1016/j.worlddev.2014.03.023

Francis C, Lieblein G, Gliessman S, Breland TA, Creamer N, Harwood R, Salomonsson L, Helenius J, Rickerl D, Salvador R et al. (2003) Agroecology: The Ecology of Food Systems. J Sustain Agr 22:99–118, doi:10.1300/J064v22n03_10

Gaventa J, Cornwall A (2006) Challenging the Boundaries of the Possible: Participation, Knowledge and Power, IDS Bulletin, 37(6):122–128, doi:10.1111/j.1759-5436.2006.tb00329.x

Gayá-Wicks P, Reason P (2009) Initiating Action Research: Challenges and paradoxes of opening communicative space. Action Res, 7(3):243–262, doi:10.1177/1476750309336715

Giraldo OF, Rosset PM (2018). Agroecology as a territory in dispute: between institutionality and social movements. The Journal of Peasant Studies, 45, 545-564.

Gliessman SR (2007) Agroecology: the ecology of sustainable food systems, Boca Raton: CRC press.

Global Agriculture Report (2016) [online] retrieved from <http://www.globalagriculture.org/report-topics/hunger-in-times-of-plenty.html> [at 14 Mar 2018]

Global Nutrition Report (2016) [online] retrieved from <http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130354/filename/130565.pdf> [at 14 Mar 2018]

Greenhalgh T, Russel J (2009) Evidence-based policy making: a critique, Perspect Biol Med 52(2):304–18, doi:10.1353/pbm.0.0085

Guzmán GI, López D, Román L, Alonso AM (2013) Participatory Action Research in Agroecology: Building Local Organic Food Networks in Spain. Agroecol Sustain Food Syst 37 (1):127–46, doi:10.1080/10440046.2012.718997

Holt-Giménez E, Shattuck A, Altieri M, Herren H, Gliessman S (2012) We Already Grow Enough Food for 10 Billion People … and Still Can't End Hunger, J Sustain Agric, 36(6):595–598, doi:10.1080/10440046.2012.695331

Ioannidis J (2005) Why Most Published Research Findings are False. PLOS Med 2(8):e124, doi:10.1371/journal.pmed.0020124

Jordan T, Andersson P, Ringér H (2013) The spectrum of responses to complex societal issues: reflections on seven years of empirical inquiry. Integral Review 9(1):34–70

Kaner S, Lind L, Toldi C, Fisk S, Berger D (2014) Facilitator's Guide to Participatory Decision Making. Community at Work, San Francisco, California: Jossey-Bass.

Kemmis S, McTaggart R (2005) Participatory Action Research: Communicative Action and the Public Sphere. In: Denzin NK, Lincoln YS (eds) The Sage handbook of qualitative research. Sage Publications Ltd., 559–603.

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Mol, P, Swilling M, Thomas C (2012) Transdisciplinary research in sustainability science – Practice, principles and challenges. Sustain Sci 7(1):25–43, doi:10.1007/s11625-011-0149-x

Leach M, Scoones I, Stirling A (eds) (2010) Dynamic Sustainabilities: Technology, Environment, Social Justice, London: Earthscan

Lock K, Smith RD Dangour AD, Keogh-Brown M, Pigatto G, Hawkes C Fisberg RM, Chalabi Z. (2010) Health, Agricultural, and Economic Effects of

Adoption of Healthy Diet Recommendations, Lancet 376(9753):1699–1709, doi:10.1016/s0140-6736(10)61352-9
Méndez VE, Bacon CM, Cohen R (2013) Agroecology as a Transdisciplinary, Participatory, and Action-Oriented Approach. Agroecol Sust Food 37(1):3–18
Muhammed M, Wallerstein N, Sussman AL, Avila M, Belone L, Duran B (2015) 'Reflections on researcher identity and power: The impact of positionality on community based participatory research (CBPR) processes and outcomes. Crit Sociol 41(7-8):1045–1063, doi:10.1177/0896920513516025
Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany EC, Biryukov S, Abbafati C, Abera SF et al. (2014) Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet 384(9945):766–781, doi:10.1016/S0140-6736(14)60460-8
Pimbert M (2006) Transforming Knowledge and Ways of Knowing for Food Sovereignty, London: International Institute for Environment and Development (IIED)
Pimbert M, Wakeford T (2002) Prajateerpu: A Citizens Jury/Scenario Workshop on Food and Farming Futures for Andhra Pradesh, India. London: IIED and Sussex: IDS
Reason P, Bradbury H (eds) (2001) Introduction: Inquiry and Participation in Search of a World Worthy of Human Aspiration' in The SAGE Handbook of Action Research, London: SAGE, 1–14
Reason P, Bradbury H (eds) (2008) 'Introduction' in The SAGE Handbook of Action Research, London: SAGE, 1–14
Rosset PM, Martinez-Torres ME (2012) Rural social movements and agroecology: context, theory, and process. Ecol Soc 17(3):17, http://dx.doi.org/10.5751/ES-05000-170317
Rothwell WJ, Sullivan RL (eds) (2005). Practicing organization development: A guide for consultants. John Wiley & Sons, Vol. 27
Sage C (2013) The interconnected challenges for food security from a food regimes perspective: Energy, climate and malconsumption. J Rural Stud 29:71–80, doi:10.1016/j.jrurstud.2012.02.005
Sandelowski M, Barroso J (2002) Finding the findings in qualitative studies. J Nurs Scholarship 34 (3):213–220.
Tendall DM, Joerin J, Kopainsky B, Edwards P, Shreck A, Le QB, Kruetli P, Grant M, Six J (2015) Food system resilience: defining the concept' in Global Food Sec 6:17–23, http://dx.doi.org/10.1016/j.gfs.2015.08.001
Thompson J, Scoones I (2009) Addressing the dynamics of agri-food systems: an emerging agenda for social science research. Environ Sci Policy 12(4):386–397, doi:10.1016/j.envsci.2009.03.001
Tittonell PA (2013) Farming systems ecology: towards ecological intensification of world agriculture, Wageningen, Wageningen University.
UNCTAD – UN Conference on Trade and Development (2013) Wake up before it is too late. Trade and Environment Review 2013
van der Ploeg JD (2008) The New Peasantries: Struggles for Autonomy and Sustainability in an Era of Empire and Globalization Oxon, London and Sterling, Earthscan, 356 p
Wakeford T, Singh J, Murtuja B, Bryant P, Pimbert M (2008) The Jury is Out: How Far Can Participatory Projects Go Towards Reclaiming Democracy? In: The SAGE Handbook of Action Research: Participative Inquiry and Practice, London: SAGE Publications Ltd, 333–349
Wezel A (2009) Agroecology as a science, a movement and a practice. A review. Agron Sustain Dev 29(4):503–515, doi:10.1051/agro/2009004
Wiek A, Ness B, Schweizer-Ries P, Brand F, Farioli F (2012) From complex systems analysis to transformational change: a comparative appraisal of sustainability science projects. Sustain Sci 7:5–24 (Supplement 1), doi:10.1007/s11625-011-0148-y
Wielinga E, Zaalmink BW, Bergevoet R, Geerling-Eiff F, Holster H, Hoogerwerf L, Vrolijk M (2008). Networks with free actors. Encouraging sustainable innovations in animal husbandry by using the free actors in networks (FAN) approach. Wageningen UR. Retrieved from <https://edepot.wur.nl/22956>[at 11 Nov 2020]
World Bank (2014) 'For Up to 800 Million Rural Poor, a Strong World Bank Commitment to Agriculture'. Washington DC: World Bank. Retrieved from <http://www.worldbank.org/en/news/feature/2014/11/12/for-up-to-800-million-rural-poor-a-strong-world-bank-commitment-to-agriculture> [at 16 Jul 2017]

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Ute Rather
Editor Landbauforschung
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THANK YOU VERY MUCH!

**It was a pleasure working with you all.**

All manuscripts submitted for publication in Landbauforschung – *Journal of Sustainable and Organic Agricultural Systems* undergo a double-blind peer review process. We, the whole editorial team and the publisher, would like to express our gratitude to all colleagues listed below who acted as reviewers for this special issue. We are grateful to the time and effort reviewers donate reviewing the papers in all versions.

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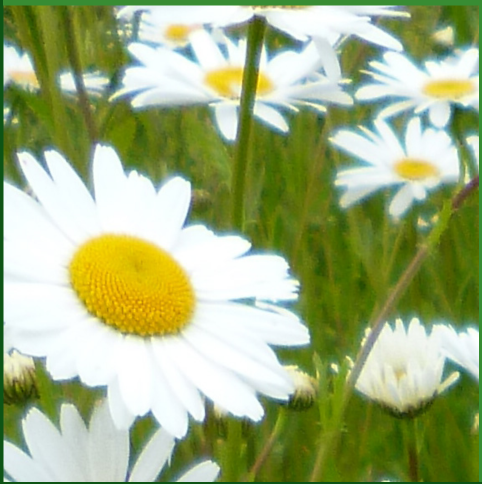

Main keywords in this issue

**Landbauforschung**
Journal of Sustainable and Organic Agricultural Systems

**Vol. 70 (2) 2020**

**Editor**
Johann Heinrich von Thünen Institute
Institute of Organic Farming
Trenthorst 32
23847 Westerau
Germany

www.landbauforschung.net

ISSN 2700-8711
Price 8 €