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REVIEW ARTICLE

Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review

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Abstract

There is consensus that the global food system is not delivering good nutrition for all and is causing environmental degradation and loss of biodiversity, such that a profound transformation is needed to meet the challenges of persistent malnutrition and rural poverty, aggravated by the growing consequences of climate change. Agroecological approaches have gained prominence in scientific, agricultural and political discourse in recent years, suggesting pathways to transform agricultural and food systems that address these issues. Here we present an extensive literature review of concepts, definitions and principles of agroecology, and their historical evolution, considering the three manifestations of agroecology as a science, a set of practices and a social movement; and relate them to the recent dialogue establishing a set of ten iconic elements of agroecology that have emerged from a global multi-stakeholder consultation and synthesis process. Based on this, a consolidated list of principles is developed and discussed in the context of presenting transition pathways to more sustainable food systems. The major outcomes of this paper are as follows. (1) Definition of 13 consolidated agroecological principles: recycling; input reduction; soil health; animal health; biodiversity; synergy; economic diversification; co-creation of knowledge; social values and diets; fairness; connectivity; land and natural resource governance; participation. (2) Confirmation that these principles are well aligned and complementary to the 10 elements of agroecology developed by FAO but articulate requirements of soil and animal health more explicitly and distinguish between biodiversity and economic diversification. (3) Clarification that application of these generic principles can generate diverse pathways for incremental and transformational change towards more sustainable farming and food systems. (4) Identification of four key entry points associated with the elements: diversity; circular and solidarity economy; co-creation and sharing of knowledge; and, responsible governance to enable plausible pathways of transformative change towards sustainable agriculture and food systems.

Keywords Agroecological practices · Food security and nutrition · Transformation of food system · Transition pathways · Social movements

1 Introduction

There is consensus that the global food system is not delivering as needed on several key metrics, including rates of hunger and malnutrition, decent agricultural livelihoods and the environmental impact of agriculture (HLPE 2019). A profound transformation is needed at multiple scales to meet the interacting challenges of increased pressure and competition

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over renewable resources, persistent malnutrition, rural poverty, increased power and concentration of agricultural and food industries, growing consequences of climatic change and alarming losses of biodiversity (FAO 2018a; IPBES 2019; IPCC 2019). While there is strong evidence that a major transformation in what food is consumed and how it is produced, processed, transported and distributed is needed to meet Sustainable Development Goal 2 (SDG2) to 'end hunger and all forms of malnutrition' by 2030, there has been less agreement on how to achieve this change (HLPE 2019). Five years ago, a major consensus building process came to fruition with international agreement on a set of 17 Sustainable Development Goals (SDGs) and 169 targets to guide an integrated plan of action applicable to all developed and developing countries (UN 2015). With respect to SDG2, sustainability in agriculture was identified as a priority, integral to addressing the grand challenge of attaining food security and healthy nutrition for all. This consensus acknowledges the need to address aspects that go well beyond a simple metric of productivity, embracing environmental and socially progressive outcomes (Caron et al. 2018; Pretty et al. 2018; Tittonell 2014). Tackling transitions to sustainable food and agricultural systems thus requires a long-term perspective and holistic approaches of the kind embodied in agroecological approaches that are increasingly recognised as having potential to facilitate the transformative change in agriculture required to meet the SDGs (FAO 2019).

Agroecology is a dynamic concept that has gained prominence in scientific, agricultural and political discourse in recent years (IAASTD 2009; IPES-Food 2016), with the United Nations (UN) Special Rapporteur on the Right to Food highlighting agroecology as a viable approach to progress towards global food security and nutrition (De Schutter 2010). In September 2014, the Food and Agriculture Organization of the UN (FAO) organised an International Symposium on Agroecology for Food Security and Nutrition, followed in 2015 by three regional meetings in Latin America, Africa and Asia (FAO 2015a, b, 2016), a further three regional meetings in 2016 in Latin America, China and Europe, and the most recent in 2017 in North Africa (FAO 2018b). A second International Symposium was convened by FAO in April 2018 entitled Agroecology: Scaling Up Agroecology to achieve the Sustainable Development Goals (FAO 2018c).

Although much more visible in the last 20 years, agroecology has a long history (Wezel and Soldat 2009). Since the first use of the term in the early twentieth century, its meanings, definitions, interpretations and approaches have evolved. Recently, there has been a proliferation of definitions of agroecology as different institutions and countries define it in ways that reflect their concerns and priorities. These definitions recognise the transdisciplinary nature of an agroecological approach which embraces science, a set of practices and a social movement (Agroecology Europe 2017; Méndez et al. 2013; Wezel et al. 2009) and the application of the concept to whole agri-food systems from food production through to consumption and all that goes on in between (Francis et al. 2003).

As a science, commonly used definitions are as follows: (i) the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions (Francis et al. 2003) or in brief, the ecology of the food system, (ii) the application of ecological concepts and principles to the design and management of sustainable food systems (Gliessman 2007); and more recently (iii) the integration of research, education, action and change that brings sustainability to all parts of the food system: ecological, economic and social (Gliessman 2018).

As a set of agricultural practices, agroecology seeks ways to improve agricultural systems by harnessing natural processes, creating beneficial biological interactions and synergies amongst the components of agroecosystems (Gliessman 1990), minimizing synthetic and toxic external inputs and using ecological processes and ecosystem services for the development and implementation of agricultural practices (Wezel et al. 2014) (Fig. 1).

Social movements propose agroecology as a solution to modern crises such as climate change and malnutrition, contrasting with the dominant industrial agricultural model based on the use of external inputs. The aim is to transform agriculture to build locally relevant food systems that strengthen the economic viability of rural areas based on short marketing chains, and both fair and safe food production. This involves supporting diverse forms of smallholder food production and family farming, farmers and rural communities, food sovereignty, local knowledge, social justice, local identity and culture, and indigenous rights for seeds and breeds (Altieri and Toledo 2011; Nyéléni 2015; Rosset et al. 2011) (Fig. 2). This political dimension of agroecology is becoming increasingly prominent (Gonzalez de Molina 2013; Toledo and Barrera-Bassols 2017). In this respect, there has been significant debate in recent years regarding how to define, interpret and pursue agroecology, with civil society voices linking agroecology to food sovereignty while often member state representatives have a contrasting position of agroecology as compatible with their view of sustainable intensification focused on approaches to increase production per unit of land to achieve food security.

Although the explicit definitions stated above reflect articulations in line with the three constituent manifestations of agroecology: a science, a set of practices and a social movement, there are interlinkages between and a co-evolution amongst these manifestations that together constitute a holistic approach (Agroecology Europe 2017; Gliessman 2018). This concurs with agroecology being increasingly described as a transdisciplinary, participatory and action-oriented approach



Fig. 1 Agroecological practices and production systems. Diversity-rich garden production in central Kenya (left—Photo A. Wezel); Multipurpose legume intercrops (pigeonpea and groundnut) next to maize fields in Malawi (right—Photo R. Bezner Kerr)

(Méndez et al. 2013; Gliessman 2018) across ecological, agricultural, food, nutritional and social sciences.

2 Methods and processes to define principles

The results presented here are based on consolidating outcomes from two initiatives. The first was carried out under the auspices of FAO to define and document a set of constituent elements of agroecology that can serve to frame and structure FAO Member Countries' engagement with this area of work (FAO 2018c). The second involved an extensive literature review related to the concepts, definitions and principles of agroecology considering the three manifestations of agroecology as a science, a set of practices and a social movement.

Principles of agroecology were analysed in terms of their historical evolution from the beginning of the nineteenth century up to the present time. Based on this, a consolidated set of principles was developed through a three-stage iterative process involving their selection (from the literature), articulation (in line with a defined notion of what constitutes a principle) and combination (to arrive at the smallest set of non-repetitious principles that captured what was articulated in the literature). This was done in the framework of the preparation of the High Level Panel of Experts (HLPE) report for the Committee on World Food Security (CFS) on 'Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition' (HLPE 2019). This review process of principles involved an open electronic consultation on an initial draft and peer review of the resulting revision. The two parallel processes (FAO and HLPE), rather than competing with each other, have informed one another, having somewhat different aims, in that the HLPE report developed the scientific basis for a set of recommendations to policy-makers, while the elements of



Fig. 2 Market situation with locally produced and marketed products. Clockwise: Organic street market in Porto Alegre, Rio Grande do Sul, Brazil, showing with diversity of products and based on short commercialisation circuit (photo K. Höök); Traditional and locally marketed dairy products in eastern Uzbekistan (photo A. Wezel); Locally produced vegetable and fruits in southern France (photo A. Wezel)

FAO are designed to structure and operationalise the assistance that FAO provides to Member Countries on agroecology, from practice to policy.

It has also to be noted that the authors of this article participated in either one or both of the FAO and HLPE processes and through this gained understanding of the issues and insights that have contributed to this article.

The HLPE report was intended to inform policy discussions and increase understanding of the ways in which agroecology can be used by civil society, governments, the private sector and other groups to address global food security and nutrition through developing sustainable food systems. To synthesise the wide range of different publications that articulate an increasing number of principles, the HLPE project team consolidated existing literature on agroecological principles into a parsimonious list of 13 statements. The consolidation mainly involved reducing the number of principles from four major sources (CIDSE 2018; Dumont et al. 2016; FAO 2018d; Nicholls et al. 2016) to a minimum, non-repetitive list by combining and reformulating them to conform to the notion of a principle as an explicit normative or causative statement that can be used to guide decision-making, action or behaviour (Patton 2018).

The 10 elements of agroecology, on the other hand, resulted from a multi-stakeholder consultation process intended to build a framework to be optimised and adapted to local contexts (Barrios et al. 2020). It was developed between 2015 and 2019 through a process involving three main phases:

1. Information gathering: An analysis was undertaken to combine the fundamental scientific literature on agroecology that includes the five principles of agroecology (Altieri 1995) and the five levels of agroecological transition (Gliessman 2015) enriched by articulation of elements in the presentations within the First International Symposium on Agroecology for Food Security and Nutrition (FAO 2015a) and the seven FAO multi-stakeholder regional and international meetings on agroecology conducted between 2015 and 2017 (see FAO 2018b for a summary of these meetings). More than 1400 participants representing 170 Member Countries and nearly 500 organisations working at local, national, regional and international levels were involved in these meetings. The selection of funded meeting participants sought to balance and diversify stakeholder representation in terms of gender and nationality.
2. Synthesis: Led by FAO experts from diverse disciplinary backgrounds with contributions from invited external agroecologists, a synthesis exercise was carried out that identified common elements from the information gathering phase and to cluster them. An initial coherent structure with fives elements emerged as central ecological features of agroecology (Tittonell 2015). In addition to these features, regional meetings expressed strong calls for reinforcing social and political aspects of agroecology. Thus, an additional five elements were added.
3. Approval by FAO: The 10 Elements of Agroecology framework (FAO 2018d) was launched at the Second FAO International Symposium on Agroecology held in April 2018 (FAO 2018c). In December 2019, following a review, revision and clearance process through FAO's governing bodies, the 10 Elements of Agroecology were approved by the 197 Members of the Food and Agriculture Organization of the United Nations to guide FAO's vision on Agroecology (FAO 2019).

On the basis of this process and consultation, FAO made a deliberate decision not to attempt to define the principles of agroecology, which they considered had been done by many knowledgeable practitioners, but rather to identify a set of salient 'elements' that can guide intergovernmental work in support of agroecological transitions towards sustainable agriculture and food systems.

3 Evolution of principles of agroecology

During its historical evolution, agroecology has expanded from the field, farm and agroecosystem scale to encompass, since the 2000s, the whole food system (Fig. 3) (Wezel et al. 2009). A broadening of topics covered along with the different manifestations of agroecology (science, practice and social movements) occurred over the decades and was reflected in an increasing number and diversity of principles.

Several different sets of agroecological principles can be found in the scientific literature—Reijntjes et al. (1992), Altieri (1995), Altieri and Nicolls (2005), Stassart et al. (2012), Dumont et al. (2013), Nicholls et al. (2016)—that are summarised in Migliorini and Wezel et al. (2018), and more recently by CIDSE (2018), FAO (2018d) and INKOTA (2019). The latter two speak about elements of agroecology as guiding the practical implementation of agroecology. These different principles contain both normative aspects that assert values (e.g. food systems should be equitable) and causative aspects, as in scientific usage, that explain relationships (e.g. more biodiverse agricultural systems are likely to be more resilient), and are applied at different scales (e.g. field, farm, landscape or whole food system) or to different dimensions of food systems such as production or governance (HLPE 2019). Today, agroecology is associated with a set of principles for agricultural and ecological management of agri-food systems as well as some wider ranging socio-economic, cultural and political principles. These latter principles have emerged only recently in the literature, arising from the activity of social movements which use agroecology as a key foundation of their work (Fig. 3a).

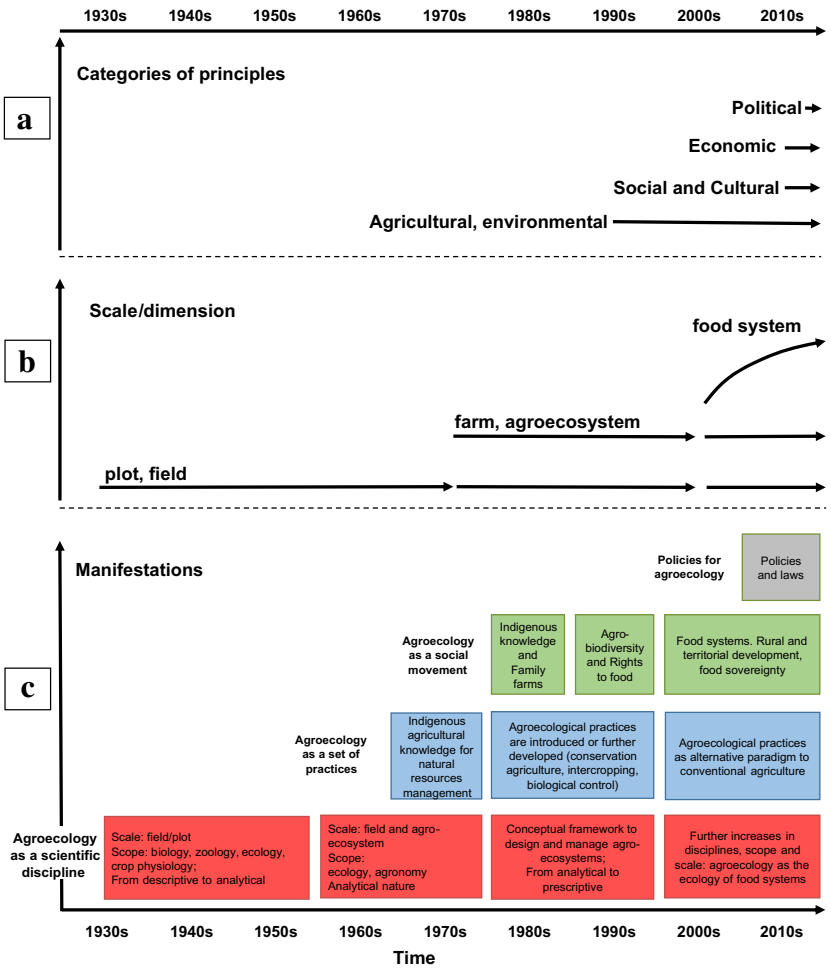


Fig. 3 Historical evolution of agroecology and its principles. **a** Disciplinary basis of principles articulated within agroecology. **b** Scales (adapted from Wezel et al. 2009). **c** Aspects, showing the emergence of the three manifestations of agroecology (science, practice and social movement) with key topics and the nature and scope of research (adapted from Silici 2014, based on Wezel et al. 2009 and Wezel and Soldat 2009). Note that indigenous knowledge and practice predate the 1980s as well as older forms of indigenous agroecology that existed prior to the formal sciences

It is argued by many that so-called industrial agricultural systems require systemic change to become sustainable and to address food security and nutrition (FSN), and that simply implementing some practices and changing some technologies are not sufficient, rather the application of agroecological principles and a redesign of farming systems is required (IPES-Food 2016; Nicholls et al. 2016). Some of these principles refer more specifically to the promotion of ecological processes and services including soil, water, air and biodiversity aspects (Nicholls et al. 2016). They include the following: (i) recycling of biomass; (ii) enhancement of functional biodiversity; (iii) provision of favourable soil conditions for plant growth; (iv) minimisation of losses; (v) diversification of species and genetic resources in the agroecosystem; and (vi) enhancement of beneficial biological interactions and synergies. The principles of Nicholls et al. (2016) are based on five principles previously articulated by Reijntjes et al. (1992) in relation to low-external-input and sustainable agriculture. For agroecological practices involving animals, Dumont et al. (2013) added other more specific animal production principles of (i) adopting management practices aiming to improve animal health and (ii) enhancing diversity within animal production systems to strengthen their resilience. Peeters and Wezel (2017) defined agroecological principles specifically for grass-based farming systems. Stassart et al. (2012) and Dumont et al. (2016) added further socio-economic principles for agroecology relating to social equity, democratic governance, creating collective knowledge, financial independence, market access and autonomy, and diversity of knowledge and experience.

CIDSE (Coopération Internationale pour le Développement et la Solidarité) (2018) also developed, together with different civil society organisations, a set of principles of agroecology. They grouped the different principles into four categories: environmental, socio-cultural, economic and political. Some of these principles refer to the demand and visions of many civil society organisations and their quest to support smallholder and family farming and sustainable livelihoods in the Global South with fair production and market conditions. Similarly, the network of INKOTA (Information, Koordination, Tagungen) (2019) defined 10 co-equal elements to best exploit the potential of agroecology which highlighted elements related to rights, participation, control over livelihoods and voice in decision-making.

FAO (2018d) first described the 10 elements of agroecology which are diversity, co-creation of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food traditions, responsible governance, and circular and solidarity economy (for more details see Barrios et al. 2020).

In the interest of bringing these many perspectives on agroecology principles to a confluence, the HLPE (2019) report synthesised the wide range of different publications that articulate an increasing number of principles, existing statements of principles and elements, and consolidated them into a list of 13 principles (Table 1) which comprise both normative and causative statements.

All principles correspond to one or more of the FAO elements (Table 1). All of the FAO elements correspond to principles, while resilience has additional attributes as an expected outcome in terms of system performance from the application of the principles, rather than being a principle itself. The principles are explicit about ensuring soil and animal health whereas these aspects are embedded in the elaboration around several elements and the principles distinguish biodiversity and economic diversification that are conflated in the single element of diversity. Whereas the consolidated principles are articulated as actionable statements containing normative (e.g. ensure animal health and welfare) and causative (e.g. greater participation in decision-making supports decentralised governance and local adaptive management) aspects, the FAO elements are different in nature from one another. For example, the elements resilience and efficiency are measurable system properties or outcomes, whereas the elements responsible governance as well as circular and solidarity economy relate to how food systems should be governed and improved. Efficiency is a broad concept relating outputs to inputs, so that many different efficiencies can be envisaged and in agriculture, increasing one efficiency ratio such as yield per unit of land or labour has often been associated with reduction in other efficiencies such as yield per unit of fossil fuel input or biodiversity loss (Sinclair 2017). A key feature of the consolidated principles is that while they are generically formulated, in practice, they are locally applied, generating a diversity of agroecological practice suited to local circumstances (Sinclair et al. 2019). In this regard, co-creation of knowledge, embracing equitable involvement of a range of stakeholders and especially the local knowledge of farmers in developing locally adapted practice, is central to both the set of consolidated principles and the FAO elements and a key tenet of transdisciplinary science in an agricultural context (Sinclair and Coe 2019).

4 Principles related to food security and nutrition

An important question for sustainable development based on agroecology, particularly in countries of the Global South, is how the agroecological principles relate to FSN. If they are applied, six out of the 13 (2, 5, 7, 10, 11, 13) could be expected to make a direct contribution to FSN, whereas for seven (1, 3, 4, 6, 8, 9, 12), impacts would be less direct. For example, reducing the dependency on purchased inputs (2) can reduce food insecurity especially for small-scale food producers. This is because less money is spent on buying inputs and so there is less reliance on credit, and therefore, potentially more resources to buy food (Hwang et al. 2016; Kangmennaang et al. 2017; Snapp et al. 2010) although potential trade-offs might exist, since depending on quantity and type of inputs, crop yields could be affected negatively, and thus increase food insecurity. Alternatively, some agroecological practices could involve more labour that if disproportionately done by women could worsen children's nutritional status unless gender relations within households were appropriately addressed (Bezner Kerr et al. 2019a). Higher labour requirements could also mean increased employment opportunities both in agriculture and agri-food businesses, as one review found for diversified farming systems (Garibaldi and Pérez-Méndez 2019). These trade-offs need to be considered in the specific food system context that they occur. An important positive impact on FSN can be expected through applying the principle of economic diversification (7) with higher diversity of on-farm incomes to ensure greater financial independence and more resilience to price volatility (Kanmennang et al. 2017). Application of the social values and dietary principle (9) impact nutrition directly, supported by maintaining and enhancing biodiversity (5) on fields and farms (Bellon et al. 2016; Bezner Kerr et al. 2019b; Demeke et al. 2017; Jones et al. 2014; Lachat et al. 2018; Powell et al. 2015).

A just food system (Pimbert and Lemke 2018) addresses wages and working conditions within it (principle 10—fairness) creating a direct link to FSN. Improved livelihoods for farm labourers, producers, small-scale distributors, market intermediaries, entrepreneurs and processors may enable them to achieve higher incomes and, therefore, purchase food. Increased proximity of producers and consumers and re-embedded local food systems (principle 11—connectivity) may contribute to improving local economies. For example, producers can profit from getting a higher share of revenue if less is taken by intermediaries over a long supply chain for marketing and distribution of produce. Also, local food enterprises and retailers can increase their price margins and become better linked and known to local consumers. Local food efforts that do not, however, address systemic issues of low wages and incomes, often linked to other issues such as systemic racism, can also reinforce and widen inequities in access to fresh, local food (Alkon and Agyeman 2011). An important point here is that producers can respond more effectively to the food needs and demand of local consumers, but addressing questions of fairness is critical. This

Table 1 Consolidated set of 13 agroecological principles, their scale of application and correspondence to FAO elements of agroecology. *FI*, field; *FA*, farm; agroecosystem; *FS*, food system

Principle	Scale of application	Correspondence to FAO elements
1. *Recycling*. Preferentially use local renewable resources and close as far as possible resource cycles of nutrients and biomass.	FI, FA	Recycling
2. *Input reduction*. Reduce or eliminate dependency on purchased inputs and increase self-sufficiency.	FA, FS	Efficiency
3. *Soil health*. Secure and enhance soil health and functioning for improved plant growth, particularly by managing organic matter and enhancing soil biological activity.	FI	Reflected in diversity, synergies and resilience
4. *Animal health*. Ensure animal health and welfare.	FI, FA	Reflected in resilience
5. *Biodiversity*. Maintain and enhance diversity of species, functional diversity and genetic resources and thereby maintain overall agroecosystem biodiversity in time and space at field, farm and landscape scales.	FI, FA	Part of diversity
6. *Synergy*. Enhance positive ecological interaction, synergy, integration and complementarity amongst the elements of agroecosystems (animals, crops, trees, soil and water).	FI, FA	Synergies
7. *Economic diversification*. Diversify on-farm incomes by ensuring that small-scale farmers have greater financial independence and value addition opportunities while enabling them to respond to demand from consumers.	FA, FS	Parts of diversity as well as circular and solidarity economy
8. *Co-creation of knowledge*. Enhance co-creation and horizontal sharing of knowledge including local and scientific innovation, especially through farmer-to-farmer exchange.	FA, FS	Co-creation and sharing of knowledge
9. *Social values and diets*. Build food systems based on the culture, identity, tradition, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets	FA, FS	Human and social values Culture and food traditions
10. *Fairness*. Support dignified and robust livelihoods for all actors engaged in food systems, especially small-scale food producers, based on fair trade, fair employment and fair treatment of intellectual property rights.	FA, FS	Part of human and social values
11. *Connectivity*. Ensure proximity and confidence between producers and consumers through promotion of fair and short distribution networks and by re-embedding food systems into local economies.	FA	Part of circular and solidarity economy
12. *Land and natural resource governance*. Strengthen institutional arrangements to improve, including the recognition and support of family farmers, smallholders and peasant food producers as sustainable managers of natural and genetic resources.	FA, FS	Responsible governance
13. *Participation*. Encourage social organisation and greater participation in decision-making by food producers and consumers to support decentralised governance and local adaptive management of agricultural and food systems.	FS	Part of human and social values

Text in italics show the titles of the repective principle

latter point is strongly supported by social organisations which foster greater participation and decision-making (or agency) of food producers and consumers (principle 13—participation).

The other seven principles are more indirectly linked to FSN. For instance, principles 1 (recycling), 3 (soil health) and 4 (animal health) support optimizing and securing agricultural production and therefore also potentially food security. While critically relevant to food security, particularly in regions with low agricultural yields, recent research documents that they are not sufficient on their own. These studies have noted that for agroecology to significantly impact food security and nutrition and generate sustainable diets, power inequalities must be addressed within food systems at multiple scales (Bezner Kerr et al. 2019a, b; Mier y Teran Gimenez Cacho et al. 2018; Pimbert and Lemke 2018). In this respect, horizontal sharing and co-creation of knowledge (principle 8—co-creation of knowledge) are important (Bezner Kerr et al. 2018; Mier y Teran Gimenez Cacho et al. 2018).

5 Transitions to more sustainable food systems

A sustainable transition occurs where there is fundamental change in a system both temporally (over a period of time) and spatially (occurring in a specific territorial location) (Marsden 2013). Transitions include political, socio-cultural, economic, environmental and technological shifts in rules, practices, institutions and values, leading to more sustainable modes of production and consumption (Marsden 2013; Pitt and Jones 2016). To examine sustainable transitions, a multi-level perspective has been used, to consider how dynamic processes and interactions across scales can support whole-system transformative change (Geels 2010; Smith et al. 2010), but also what issues of power relations drive changes or establish 'lock-ins' (IPES-Food 2018; Leach et al. 2020). Some transitions begin at a small scale, a 'niche' or protected space in which farmer cooperatives, social movements, businesses, local government or other groups

experiment with and adapt alternative ways of doing things (Geels 2010; Hinrichs 2014). These small-scale changes may foster alternative models of food systems which are either marginalised, get absorbed by, or challenge, the dominant system (Brunori et al. 2011; Elzen et al. 2017; Levidow et al. 2014). The HLPE report (2019) found that to effectively address food security and nutrition, discrete techniques or innovations and incremental interventions are not sufficient to bring about the food system transformations that are needed. The report finds that innovation for sustainable food systems requires (i) inclusive and participatory forms of innovation governance; (ii) information and knowledge co-production and sharing amongst communities and networks; and (iii) responsible innovation that steers innovation towards social issues. Examples of collaborative efforts to initiate transformative change include democratically designed 'innovation platforms', where stakeholders are brought together to coordinate amongst themselves the development of technical, social and institutional innovations (Tittonell et al. 2016). Food retail, consumption and production practices can be shifted over time through a dynamic interaction between innovations in food production, enterprises, social movement advocacy, policy and cultural change (Hinrichs 2014; Spaargaren 2011). There are clear challenges in making and keeping such processes inclusive—given that they are at the nexus of power imbalances between innovators and those guarding the stability of an existing system. In addition, social and political institutions can create pathways or 'lock-ins' which prevent transitions from occurring (IPES 2016, 2018; Smith and Stirling 2010).

The transition pathway framework of Gliessman (2007, 2016) comprises five different levels (Fig. 4). In this framework, assuming transition from an industrial or green revolution form of agriculture towards more sustainable food systems, agroecological transition pathways often begin with a major underlying focus on resource use efficiency. Agroecology addresses resource use efficiency through practices that reduce or eliminate the use of costly, scarce, or environmentally damaging inputs, thus related primarily to the principle of input reduction, but also recycling. At the second level of transition, substitution of conventional inputs that have negative impacts on the environment is envisaged, replacing them by making use of co-existing biota (such as the plant microbiome or natural enemies of pests) to improve plant nutrient uptake, stress tolerance and defences against pests and diseases (Singh et al. 2018). Whereas levels 1 and 2 are incremental, levels 3 to 5 are transformational. Level 3 is based on the redesign of farming systems to increase system diversity, improve soil and animal health, enhance diversification and recycling, reduce inputs, and increase synergies on farms and across landscapes. An example is the enhancement of diversity in farm structure and management with diversified rotations, multiple cropping, agroforestry and the (re-)integration of animals and crops. There is a strong focus on managing interactions amongst components, for example through the strategic use of crop residues as mulch or animal feed. Transition levels 4 and 5 broaden the focus to encompass the whole food system. Level 4 establishes a close relationship between people who grow the food and the people who eat it. Pathways are the development of direct sales and new alternative food networks, from farmers' markets, to community supported agriculture, to other direct marketing arrangements that aim to be fairer and more just. Finally, level 5 involves building a new global food system that is not only sustainable but also helps restore and protect Earth's life-support systems. This food system is based on participation, localness, fairness and justice, which are important human rights 'building blocks' of food security and nutrition (HLPE 2019).

Through the transition levels towards sustainable food systems, agroecology presents multiple pathways for the transformation of farming and food systems co-created to suit different local contexts, based on a social-ecological systems approach (see also Elzen et al. 2017; IPES-Food 2016). To move forward with these transitions, many factors, parameters and issues must be considered as there is a diversity of situations, with multiple pathways of agroecological transition towards more sustainable food systems, depending of the starting points, the context and the engagement with markets. The role of civil society, social movements and consumer organisations is critical to ensure transitions. Social movements such as La Vía Campesina at the global scale, and national members such as the Brazilian Landless Workers Movement (MST), are important actors contributing to debates around transition to sustainable food systems, with their varyingly political, civil societies' and peasants' views on agroecology as a means to distinguish their practices and vision for food system transformation from those that are supported by agri-food corporations and more mainstream institutions (Giraldo and Rosset 2018). These social movement actors have played a crucial role in raising the political dimensions of agroecology, providing alternative models for food systems and emphasizing the need for more systemic changes to occur, such as through grassroots farmer-to-farmer networks (Val et al. 2019).

The strong involvement of policy- and decision-makers at local, regional, national and supra-national levels, as well as farmer organisations, supply chain actors and agro-industry is required to facilitate an agroecological transition (IPES-Food 2018). The interaction and synergies between context-specific, local knowledge and academic science as well as social and institutional innovation all play a critical role in catalysing and supporting an 'epistemic' transition (Elzen et al. 2017). This includes creating stronger markets for agroecologically grown foods, developing social solidarity economies, pushing for agroecological procurement by institutions, shifting public awareness and developing inclusive governance mechanisms

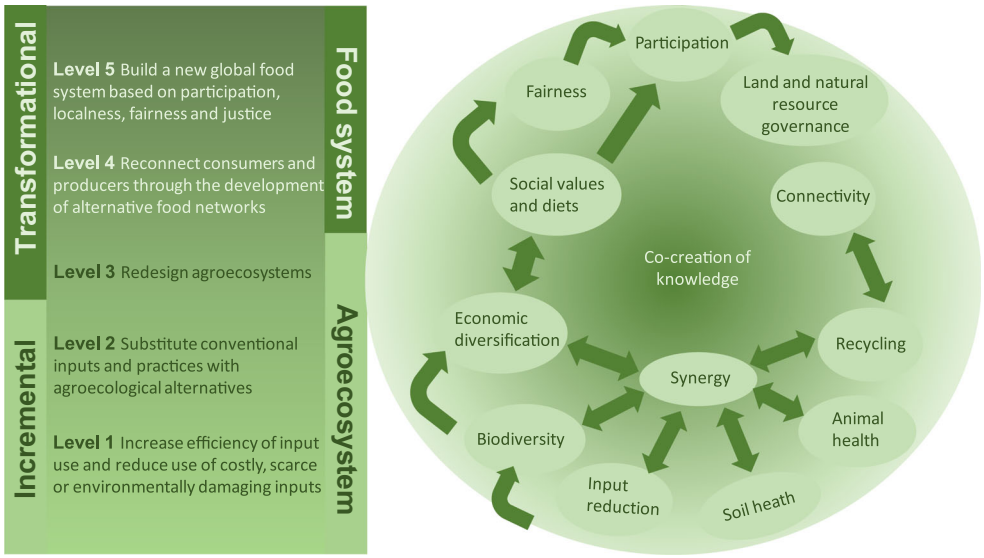


Fig. 4 Transition levels towards sustainable food systems and related consolidated principles of agroecology. The ovals on the right correspond to the agroecological principles from Table 1. Principles 1–7 (lower right hand side) relate primarily to the agroecosystem scale whereas 9–13 (upper right hand side) to the food system with co-creation of knowledge central across scales. Note: Levels adapted from Gliessman (2007). Levels 1 and 2 are incremental, levels 3–5 transformational. Arrows show major influences amongst principles

that support an agroecological transition. One study of how to transition Europe to agroecological systems in 10 years, for example, focused the initial transition discussion on reducing pesticides, supporting diversification of landscapes and shifting diets towards more fruits and vegetables and lowering meat consumption (Poux and Aubert 2018). In contrast, Brazilian social movements supporting agroecological transitions have focused on land access and developing local and fair agroecology markets with participatory guarantee systems, while in Senegal, agroecological transitions have focused on the formation of ecovillages and soil management (Ilieva and Hernandez 2018).

One of the major challenges to transformative change in agriculture is the difficulty of designing differentiated paths for food and agricultural systems transformation that respond to local and national expectations (Caron et al. 2018). In addition to the five levels described above, the FAO agroecology framework recognises all 10 elements as potential entry points for transformative change towards sustainable food and agricultural systems and the facilitative role of visual narratives and nexus analysis (Barrios et al. 2020). Four key entry points are identified in Fig. 5 in clock-wise direction and short narratives used to describe plausible transition pathways. First, the *Diversity* entry point: diversification is central to facing climate change as well as nutrition challenges because variations in agricultural use and management of plant and animal diversity can have important impacts on the adaptive capacity of agricultural systems to climate change as well as on their contribution to nutritious and healthy diets.

Second, *Circular and Solidarity Economy*: changing food consumption patterns can have major impact on markets at different scales. The increasing demand for diversified,

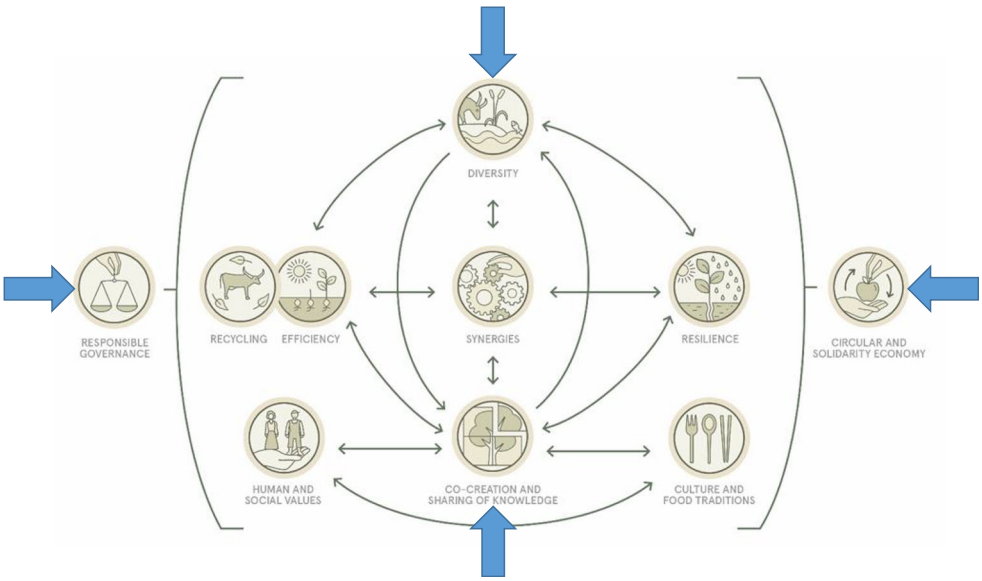


Fig. 5 Four key entry points in FAO's 10 elements of agroecology framework to build transformative change pathways towards sustainable food and agricultural systems (Adapted from FAO 2018d)

nutritious and safer food by consumers would support cleaner production, shorter-value chains, diversified markets and green jobs. These changes would require changes in the supply side through diversified agricultural systems that, in addition to contributing a broader range of products, reduce the need for external inputs as a result of greater resource use efficiency. Third, the *Co-creation and Sharing of Knowledge* entry point: promoting educational curricula at all levels to support agroecological transitions is fundamental to raise awareness and to encourage improvements in linking knowledge to action. This involves the development of capacities for holistic or systems thinking to face the increasing complexities of an interconnected world where disciplinary or sectoral approaches have had limited success. Fourth, the *Responsible Governance* entry point: transparent, accountable and inclusive governance mechanisms are necessary to create an enabling environment that supports producers to transform their systems following agroecological concepts, principles and practices. By fostering market-systems that allow for small and medium scale food enterprises, responsible governance also supports local and regional food systems. Furthermore, the transformative impact of multiple entry points can be greater through the promotion of concurrent transitions taking place via different entry points in the same territory adapted to contextual variations across the territory.

6 Conclusions

Agroecological principles have evolved in recent years to encompass social and cultural aspects of whole food systems in addition to those related to agricultural practice at field, farm and landscape scales. A consolidated set of 13 principles constructed from the literature on agroecology as manifest as a science, a set of practices and a social movement (HLPE 2019) were found to be well aligned and complementary to the 10 elements of agroecology developed by FAO. The principles, while generically formulated are locally applied, generating diverse, locally adapted agroecological practice through co-creation of knowledge with stakeholders. The principles are relevant both to transitioning agricultural and food systems to achieving global food and nutrition security and to building resilience of agriculture by adapting to climate change.

A further question is the implication for having this enlarged number of agroecology principles on future research. Currently, much of the research carried out related to agroecology focuses more on the first five principles and the first two food systems transformation levels of 'increased efficiency' and 'substitution' (e.g. for Europe see Wezel et al. (2018). To fully embrace the systems approach and a holistic view, future agroecology research needs to include much more interdisciplinary and transdisciplinary work and consider multiple entry-points and transition trajectories, in particular including social, cultural, political and economic issues. The core principle of co-creation of knowledge requires a very different approach to research: one that places farmers and stakeholders at the centre of defining research questions and developing solutions alongside scientists. Furthermore, to transition to a just and inclusive food system will require changes in economic policies that support local and regional food systems, raising questions of how to address power dynamics in order to shift the dominant narrative (Anderson et al. 2020). The social and political principles of participation, fairness, connectivity and land and natural resource governance all highlight the need for research and advocacy related to these changes, required for a true transformation of food systems to be resilient, equitable and sustainable.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Disclaimer The views in this article are those of the authors and do not necessarily reflect the views or policies of FAO or their own institutions.

Authors' contributions A. Wezel: writing, literature search, defining principles, editing; B. Gemmill-Herren: writing, literature search, defining principles, defining elements; R. Bezner Kerr: writing, literature search, defining principles; E. Barrios: writing, literature search, defining elements; A.L. Rodrigues Gonçalves: writing, defining principles; F. Sinclair: writing, literature search, defining principles.

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