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REVIEW ARTICLE

Levers for the agroecological transition of tropical agriculture

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Abstract
To promote greater sustainability in agriculture, development of agroecology is increasingly being invoked. What are the conditions for establishing agroecological production in tropical regions? Based upon case studies in several tropical areas, we provide here some answers to this question. We review the "pillars" (i.e. principles) and the "implementation levers" (i.e., tools) for the development of agroecology. We identify three main pillars: (1) the mobilization and management of ecological processes for the sustainable production and the resilience of agroecosystems; (2) the development of interactions between technical, social, environmental, and institutional components of agroecosystems for a holistic approach to agroecology; and (3) the scaling up of agroecology that takes place with a plurality of actions and pathways at different organization levels rather than an increase in resources and a replication of standardized technical processes. To implement these three pillars, we identify 11 main bio-technical, cognitive, socio-political, and organizational levers. Bio-technical levers include those for (1) mobilizing complementarity between crop species to optimize natural resources use, (2) mobilizing functional biodiversity at the plot scale to optimize natural regulation of pests and diseases, (3) managing biodiversity at landscape and territorial scales, (4) increasing the efficiency of biogeochemical cycles, and (5) renewing targets for genetic improvement. Cognitive, socio-political, and organizational levers include those for (6) political and institutional action at the national and global level, (7) action at the local level to support producers, (8) political and organizational action at the territorial level, (9) the marketing and the development of new agri-chains, (10) the development of new methods for evaluating production systems, and (11) the recognition of the values of gender and generation within families and other organisational levels. This paper provides an overall orientation for the agroecological transition in tropical agriculture and also considers the socio-political context that underlies this transition.

Keywords Biodiversity management · Agroecological crop protection · Agri-food chains · Institutional and political rules · Territorial development in the global South

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Contents

1 Introduction

Agricultural systems in the tropics, where many countries are still facing sharp increase in human population, are challenged by a growing food demand, unequitable food availability and structural economic conditions that are not favourable to rural employment. As is the case for agriculture in northern countries, these challenges in tropical countries are accompanied by the need to reduce rural poverty, to maintain an equilibrium between rural and urban areas, to preserve natural resources, to attain more sustainable and safe food systems, and to cope with climate change (HLPE 2019).

World agriculture has rapidly evolved during the last 60 years and has managed to fulfil a rising global food demand. This success, however, has been based on the cheap mining of renewable resources (land, soil fertility, water, and biodiversity) which has largely exceeded the capacity to recover for many ecosystems and resources (Wezel et al. 2009; Gliessman 2015; Altieri 2018). Another drawback of agricultural development in these past decades is that it has been unevenly shared among countries. Many countries have been unable to substantially increase their food production even though those countries are exactly where the population is still rapidly growing and where food challenges are and will be particularly acute in the next decades. Since 2015, FAO's investment strategy has promoted agroecology (FAO 2015). However, conventional agriculture is still often promoted in tropical areas. Agroecology is sometimes questioned or perceived as an obstacle to meet the growing food demand, while its defenders insist on the urgent need for a radical transition (Gliessman 2015; HLPE 2019).

The objective of this paper is to review research and development experiences from tropical regions in Africa, Asia, Latin America, the Indian Ocean, and the Caribbean and to also highlight the challenges for developing agroecological systems. This analysis of agroecology is mainly based on reflections and references of the Centre for International Cooperation in Agricultural Research for Development (CIRAD) and the French Development Agency (AFD). The first part of the article presents an interpretation of agroecology principles. The second part is devoted to the levers, i.e., the tools that can help effective agroecological systems (Fig. 1).

2 Agroecological pillars for tropical regions

Fundamental principles of agroecology have been proposed by various authors (Wezel et al. 2009; Altieri et al. 2017). The definitions of agroecology are numerous and are still the subject of controversy. Our purpose is not to provide another definition of agroecology but to deliver an operational interpretation of its principles., i.e., its pillars.

We identify three operational pillars. The first relates to mobilizing and managing ecological processes to ensure the provision of a set of services aimed at preserving renewable resources. This is undoubtedly the most commonly accepted principle when referring to agroecology, and all the promoters of tropical agroecology subscribe to this principle (Malézieux 2012). The second pillar consists of those connections that must be established between the technical, social, environmental, and institutional components of agroecosystems in order to develop agroecology. Technical changes can be achieved at the cropping or livestock system scale, but the overall agroecological transition requires changes in the organization at farm, landscape, regional, and agri-chain levels, jointly with an evolution of public policies and consumer initiatives at national and global levels (Tittonell et al. 2016; Cerdan et al. 2019). This holistic approach is mainly justified by the need to manage increasingly scarce and fragile resources used by multiple actors with divergent interests not only at the territorial scale but also at national and international scales (Piraux et al. 2019;

Fig. 1. Examples of multispecies production systems especially suited to a transition to agroecology. **a** An agroforestry system for local production based on bananas and coffee (photograph by B. Rapidel). **b** An export banana and cover crop system (photograph by H. Tran Quoc).

Toillier et al. 2019) and at the level of markets and value-chains (Cerdan et al. 2019). This second pillar leads to the close linking of agroecological transition to the transition to sustainable food systems (Gliessman 2015).

The third founding pillar we highlight involves the dynamic dimensions of the transition itself. The scaling up of agroecology of course depends on the starting point, i.e., on the degree of development of the two first pillars. However, scaling up in agroecology is different from scaling up in the Green Revolution. Scaling up in agroecology proceeds with a plurality of actions and pathways. In contrast to the green revolution, agroecology is at the opposite developing standardized systems because it depends on the hybridization between local and scientific knowledge and on the use of local biological and ecological resources shared by various actors. The classical notion of "scaling up," which assumes that the same innovative systems developed in small area can be replicated in larger areas by many other farmers by simply increasing allocated resources, is thus not consistent with agroecology. For agroecology, scaling up should be replaced be the idea of "agroecological transition": a contextualized, progressive, and diversified systems' transformation (Côte et al. 2019).

The first two pillars we propose here are in line with and combine the 10 elements of agroecology described by the FAO (FAO 2015) and the 13 elements of agroecology reported by the HLPE (HLPE 2019). These pillars represent of these elements formulated by these two institutions. The third pillar, which is conceptually similar to ideas proposed by (Gliessman 2015), emphasizes that upscaling should involve the notion of territorial agroecological transition.

Based on our experiences, we suggest that all of the diverse production systems in the tropics can be part of a process of environmental progress through the adoption of agroecology principles, independently of their initial degree of artificiality, productivity, or diversity (Côte et al. 2019). We also believe that agroecology should not be seen as a slogan or a one-way process that excludes the use of improved varieties, mechanization, or exogenous inputs when yield gap is important. We believe that an in-depth agroecological transformation, when accomplished, should be free of synthetic pesticides and should be parsimonious in the use of synthetic fertilisers.

Because of its holistic perspective and because it values local knowledge and practices, territorial anchorage, and diversity (biological and organizational), we consider agroecology is particularly important for small-scale farms and their economic and social networks. Social movements fighting for agroecology intersect with movements in favor of family farming and alternatives to globalized markets in Latin America (Le Coq et al. 2019) or Africa (AFSA, Alliance for Food Sovereignty in Africa; DyTAES, Dynamique pour la Transition Agroécologique au Sénégal). In contrast, large-scale intensification through industrialization (we consider here mostly large-scale industrial plantations for exportation) usually results in a degree of uniformity (of landscapes, plants, etc.) and social status that does not appear compatible with several principles of agroecological production systems. Concentration often interferes with resource allocation equity and specialization is inconsistent with diversity and promotes distance over proximity. Although large industrial farms can also reduce their use of synthetic inputs and decarbonize their systems, these changes must go far beyond a simple "greening" of their policies and communication.

3 Levers for agroecological transition in the tropics

Here, we describe the major levers for the development and implementation of the three pillars described in the previous chapter.

3.1 Biotechnical levers

From our experience, we distinguish five main biophysical levers for the design of new agroecological systems for tropical regions. All of these levers are based on the role of biodiversity in sustainable production systems. The levers include (i) the optimizing of natural resource use and the maximizing of photosynthesis, (ii) the mobilizing of functional biodiversity at the plot scale, (iii) the managing of biodiversity at the landscape and territorial scales, (iv) the renewing of targets for the genetic improvement of plants and animals, and (v) the increasing in the efficiency of biogeochemical cycles. These biotechnical levers are described in greater detail in the following paragraphs.

3.1.1 Levers for optimizing natural resource use, maximizing photosynthesis, and increasing resilience

Complementarity between phenotypes and species over time may be optimized in order to increase resource-use efficiency at the field or the landscape scales. In agroforestry systems, species are selected to complement rather than to compete with each other (Salazar-Díaz and Tixier 2021) and finally to increase farmer incomes (Salazar-Díaz and Tixier 2019). Tropical systems with greater species diversity improve the use of natural resources in general and the use of solar energy, atmospheric carbon dioxide, water, and nitrogen and other nutrients (Malézieux et al. 2009). For example, the complementarity between trees and annual crops improves the use of aboveground and belowground resources for systems involving the leguminous tree *Faidherbia albida* in the semi-arid zone of West and East Africa or for systems involving *Coffea arabica* in Central America (Roupsard et al. 1999; Lahmar et al. 2012; Padovan et al. 2015). Crop diversification, i.e., the mixing of plants at the plot scale, can significantly increase biodiversity, production, and other ecosystem services. That this effect is widely shared among a wide range of agriculture systems worldwide was indicated by a recent meta-analysis (Beillouin et al. (2021).

Biomass production per unit area could be increased by using cover plants, intercropping species and rotations in different tropical agriculture systems (Scopel et al. 2013; Ranaivoson et al. 2017). The engineering of multispecies cropping systems has made significant progress as shown in the banana culture systems in the French West Indies (Tixier et al. 2011). The use of the concept of functional traits makes possible the selection of the most suitable cover plants according to the expected services and the local context (Damour et al. 2014; Tardy et al. 2015). The complementarities between the culturing of plants and livestock are also at the heart of interactions between species that optimize the use of resources. Co-designing innovative mixed crop-livestock farming system remains a key factor of agroecological transition in, for example, cotton cropping areas of Burkina Faso (Vall et al. 2019).

3.1.2 Levers for mobilizing functional biodiversity at the plot scale to optimize the natural regulation of pests and diseases and to reduce the use of pesticides

Because they can develop throughout the year, pests and diseases often cause significant production losses under tropical conditions. The type and intensity of both aboveground and belowground natural enemies of pests and diseases are influenced by the diversity of plant and animal communities in tropical agroecosystems (Poeydebat et al. 2017; Poeydebat et al. 2018). The use of plant biodiversity can reduce pests and disease via many processes including resource dilution, diversion, conservation, and predation (Ratnadass et al. 2012). Regulatory processes can also be intensified in the soil by promoting allelopathic effects and by stimulating antagonistic agents (Ratnadass et al. 2012). Even though the mechanisms underlying the regulation of pests and pathogens by natural enemies are only partially understood, the following agroecological practices have been found to increase the biological regulation of pests and diseases: the mixing of rice varieties in Madagascar (Raboin et al. 2013), the introduction of cover plants in banana and sugarcane plantings (Mollot et al. 2014; Nibouche et al. 2019), the use of non-host plants in crop rotations, and the introduction of repellent or attractive plants in horticulture (Deguine et al. 2015).

3.1.3 Levers for managing biodiversity at the landscape and territorial scales

Functional biodiversity should be managed not only within the plot but also outside the plot by the use of ecological structures such as hedges, ditches, trees, and grass strips. The intelligent arrangement of the environment makes it possible to extend the habitat of some regulating natural enemies and may thus strengthen the control of certain pests and diseases in, for example, banana plantings (Tixier et al. 2013). Functional biodiversity can be managed at the watershed or the landscape level through the creation of ecological corridors (Lestrelin et al. 2019). The integration of a mosaic organisation at the landscape level also helps to preserve critical resources (biodiversity, water, and soil) and to limit the flows of sediments, nutrients, and pesticides towards the natural environment as shown, for example, in the Caribbean (Cattan et al. 2019).

3.1.4 Levers for contributing to the efficiency of biogeochemical cycles

Limiting the degradation of natural resources and the disruption of natural processes caused by ecosystem simplification is a main challenge in tropical areas where soils are poor or degraded. The degradation and disruption caused by simplification can be reduced by maintaining a permanent plant cover on the soil surface in all tropical systems studied to date. A permanent plant cover limits erosion and soil compaction, promotes rainwater infiltration and groundwater recharge, and reduces nutrient losses from runoff in agroecosystems in Central America (Benegas et al. 2014; Meylan et al. 2017). This practice may contribute to the preservation of water and nutrient resources, both quantitatively and qualitatively, in small-scale farming systems in the dry zones of Mexico (Scopel et al. 2005) and in the more humid Brazilian Cerrados (Silva et al. 2019). The protection of the soil surface by a permanent cover also reduces the variation in soil temperature and humidity and thereby promotes biological soil functions. However, two main drawbacks to the adoption of permanent cover by small-scale farmers remain (especially for farmers who grow annual crops such as cereals and legumes): the initial planting of the main crop in an already-installed cover often relies on chemical herbicides, and the planting and maintenance of a cover crop can require substantial manual labour (Perret and Stevens 2006; Affholder et al. 2010).

3.1.5 Levers for renewing targets for genetic improvement of plants and animals

The search for biological functional diversity should first focus on the richness of existing traditional cultivars produced by farmers and already adapted to complex systems. Regarding the development of new cultivars for use in agroecosystems, an agroecological perspective means that breeders of plants and animals will be selecting for new traits that often differ from those previously selected (Raboin et al. 2013; van der Vossen et al. 2015). Breeding programs should now focus on traits and ideotypes so that the potential interactions of plants, animals, and their environment are better considered. For example, *arabica* coffee plantations often produce less in agroforestry systems than in full-sun plantations (Bertrand et al. 2011). For decades, coffee varieties have been bred in full-sun to reduce heterogeneity. In contrast, the varieties that proved successful in agroforestry systems to date have been obtained "by chance" and not by a breeding strategy (Bertrand et al. 2011). It is now time to intentionally breed varieties that will be useful for agroecological systems. It is also time to reconsider the strategy of variety deployment. In contrast to the agroindustrial goal in recent decades, which often was to breed and deploy a "perfect," all-purpose genotype, the agroecological goal should be to breed and deploy sets of genotypes covering a wide range of abiotic and biotic environmental conditions (Côte et al. 2019).

3.2 Cognitive, socio-political, and organizational levers

We identify six cognitive, socio-political, and organizational levers to promote the agroecological transition: (i) political and institutional levers for action at the national and global level; (ii) levers for action at the local level to support producers; (iii) political and organizational levers for action at the territorial level; (iv) levers for marketing and the development of new agri-chains; (v) levers for new methods for evaluating production systems; and (vi) gender and generational levers within families and other organisational levels. These levers are described in greater detail in the following paragraphs.

3.2.1 Political levers for action at the national and global levels

Agroecological transition requires organizational, technical, disruptive, or transformative changes. Development of agroecology fundamentally depends on the adoption of dedicated national policies and the ability of such policies to impart value to the services and multiple functions of agricultures. National authorities or governments should promote, evaluate, and support approaches that address the trade-offs between agricultural, rural, environmental, food, and social policies as observed in Latin American countries (Le Coq et al. 2019). In our experience, the agroecological transition has often arisen from spontaneous local initiatives. However, the institutionalization of the transitions depends on national policies and markets, as well as a recognition in international agendas. In Sub-Saharan Africa, for example, agroecology is a credible solution for the structural economic challenges, but the conventional vision of modernization and artificialization of agriculture remains often dominant at national and regional levels (Losch 2016). The Green Revolution still benefits, at national and international levels, from the significant amounts of direct and indirect funding (soft loans and investments in infrastructure, research, support services, etc.), and from direct and indirect subsidies through market policies. The development of the agroecological transition will likely require a comparable level of aid. The zero-input "natural farming" policies in Andhra Pradesh, India, illustrate a spectacular transformation managed by political action (Dorin 2022).

The differences of perception of priorities in the short- ang long-term between the different actors still constitute a major challenge in the advocacy and implementation of the agroecological transition at national and global levels. Compared to the establishment of governance concerning private goods, the establishment of governance concerning common goods often takes much longer because it requires collective rather than individual dynamics. Therefore, governments are tempted by known solutions, even when the evidence indicates that known solutions have negative results.

A bias in favour of the agroindustry rather than the agroecological systems may also exist in political decision-making, reinforced by alarming narrative from transnational corporations and their networks, and sometimes relayed by global farmer organizations (Fouilleux et al. 2017; Bricas and Malézieux 2021). The objective to feed an increasing population that will reach 9 billion in 2050 has long been used to justify chemical intensification practices in order to double world production. There is some evidence that agroecological practices, in addition to providing more ecosystem services than conventional agriculture, can also increase agricultural productivity (Beillouin et al. 2021). It follows that the benefits but also limits of agroecological systems should continue to be scientifically documented and compared with the benefits and limits of conventional systems at different spatial and temporal scales.

3.2.2 Levers for action at the local level to support producers

The various agroecological transition pathways should be embedded, designed, and implemented in local systems in an adaptive and collaborative way. Researchers have reported that small farmers in the tropical countries must play a central role in the transition to agroecology (Le Coq et al. 2019; Sourisseau et al. 2019; Toillier et al. 2019). Local farmer innovations are frequently useful for transforming traditional systems into agroecological systems (Périnelle et al. 2021). Some support mechanisms like innovation platforms (i.e., groups of individuals with different backgrounds but common innovation goals) can help resolve problems that producers and other actors encounter during the agroecological transition. As observed in different contexts in Africa (Dabire et al. 2017; Angbo-Kouakou et al. 2018), the success of these platforms is based upon several principles: construction and exchange of knowledge between actors; facilitation of collective action; strengthening or development of collaborative practices between multiple organizations with sometimes divergent interests; and facilitation of planning of action and the monitoring, evaluation, and capitalization of experimental activities.

The transition to new agroecological systems also requires increased involvement of support services. The transition would benefit from advisory approaches based on field-schools (Bakker et al. 2021), exchanges between farmers and farmer leaders, and digital technologies. Non-governmental organizations (NGOs) and producer organizations are also required to promote the agroecological transition through activities of training, research, and development.

3.2.3 Political and organizational levers for action at the territorial level

Making the best use of a territory's tangible and intangible resources is essential for an agroecological transition. A territorial asset consists of an institutional arrangement formalized between territorial actors (producers, service providers, value and supply chains, policy makers, civil society, etc.). This level of organisation differs from the innovation platforms previously described, which are more focused on producers and their immediate environment. Support at the territorial level involves larger scales and public decision-makers. The objectives of a territorial approach include identifying trade-offs between actors willing to promote agroecology and territorial development, and proposing new values, standards, and rules, as described for the Brazilian Amazon by Piraux et al. (2019). The management and quality of information are crucial for territorial development because the information that is produced must be relevant, usable, and actually used (Tonneau et al. 2017). This complements the need to move away from a project-based approach and to instead develop long-term local policies (Boillat et al. 2022).

3.2.4 Levers for marketing and the development of new agri-chains

The adoption of agroecological practices may reduce yields and increase producer costs for labour, certification, monitoring, and sometimes inputs. Incentives and financial compensation sometimes help the agroecological transition, but the transition must also be facilitated by new market dynamics with an emphasis on direct sales and short supply chains. Cerdan et al. (2019) described various examples of agroecological practices in Brazil, Morocco, Vietnam, Madagascar, and Laos promoted by markets. Agroecology and the concept of the localized agri-food system involve new agreements, bringing together innovative practices, processing, and marketing functions (Marie-Vivien and Biénabe 2017; Meynard et al. 2017).

3.2.5 Levers for new methods of evaluating production systems

Whether biotechnical or organizational, the levers described above can only be effective if a framework for the evaluation of the system performance is in place. The framework for evaluation of new agricultural production systems will differ from that used for conventional agriculture production systems because new agricultural production systems provide a much wider range of goods and services (Malézieux et al. 2009; Affholder et al. 2019). A framework for the evaluation of ecosystems based on sustainability has emerged over the past 20 years and is well adapted for the evaluation of agroecological systems (Lairez et al. 2016). Initiatives and projects are also developing specific evaluation processes for agroecology (Tittonell 2020). The TAPE (Tool for Agroecology Performance Evaluation) agroecological system assessment initiative launched by FAO is one of the most advanced of these initiatives; TAPE includes a participatory diagnosis of the strong and weak points of the production systems in place (Mottet et al. 2020).

Given the current stage of development of agroecology, a set of "demonstrators" under real conditions and in different contexts must be deployed to specify and evaluate the level of economic, social, and environmental performance of the agroecological solutions envisaged. Based on these demonstrators and their scientifically documented evaluation data, effective advocacy can be offered to decision-makers and civil society. Such an approach is part of the European Commission's programme on value chain analysis (VCA4D). Recent case studies with multicriteria analysis and Life Cycle Assessment (LCA) standardized methods improve the policy dialogue and action plans of producers. Examples from the Dominican Republic (banana) (Feschet et al. 2019), Cameroon (cocoa) (Lescuyer et al. 2019), Mali (cashew) (Michel et al. 2019), and Angola (coffee) (Bessou et al. 2020) demonstrate the economic, social, and environmental benefits and limits provided by agroecological production practices. To date, case studies in more than 35 countries have been carried out within the VCA4D programme.

3.2.6 Gender and generational levers within families and other social organizations

A major challenge for the future of agroecology is linked to the transformation of the roles of women and youth, on their own and as parts of families, in agriculture. An intra-household balance of power is crucial to support technical, social, and economic innovation of family agriculture, from production to product transformation and commercialization (Ancey and Fréguin-Gresh 2015). Agroecological transition may therefore benefit from an increase in the access of women and youth to production resources, social capital, and decision-making. Women and youth have specific knowledge and skills due to their former marginalized positions. For example, women may tend to focus more than men on worker care, safe practises, safe products, and the sustainability of farms and territories (Bezner et al., 2019; Zaremba et al. 2021).

Job creation in agriculture and in food systems in general is a major challenge, especially in Sub-Saharan Africa, which is experiencing explosive growth in human populations (Losch 2016). The development of the agroecological transition may in this context have a crucial role to play. Because of the complexity of agroecological systems in terms of diversity of species and interactions to be managed, manual labour is often more important in agroecological systems than in those simplified systems that depend on large inputs of synthetic fertilizers and pesticides. However, the fact that agroecology create more jobs has to be demonstrated (Paracchini et al. 2020). The attractiveness of agricultural jobs depends greatly on the salary offered and on the place of agriculture and food sovereignty for the citizens (Giordano et al. 2019).

Table 1 summarizes the 11 levers that we identify to implement agroecology. In this table, we indicate the spatial scales at which these levers would be deployed. The scales range from the plant to the global, this underlines the systemic nature of the implementation of the agroecological transition. These levers are complementary, creating outcomes that are difficult or even impossible to achieve if pursued independently as it is the case in most innovation processes in agriculture involving a major paradigm shift (Toillier et al. 2022).

Table 1. Levers for agroecology in tropical agriculture.

Scale	Biotechnical levers	Cognitive and socio-political and organizational levers	
Plant	Levers for renewing targets for genetic improvement of plants and animals	Levers for action at local level to support producers	Levers for marketing and the development of new agri-chains Levers for new methods of evaluating production Gender and generational levers
Plot and farm	Levers for optimizing natural resources use, to maximize photosynthesis and to increase resilience Levers for mobilizing functional biodiversity at the plot scale, to optimize the natural regulation of pests and diseases and to reduce the use of pesticides		
Landscape/regional and global	Levers for managing biodiversity at the landscape and territorial scales.	Political and organizational levers for action at the territorial level	
Global	Levers for contributing to the efficiency of biogeochemical cycles.	Political and institutional levers for action at the national and global level	

4 Conclusion

In this overview, we have described the 11 specific biotechnical, organizational, and political levers that are needed to make the transition to agroecological systems in tropical regions. Although they differ in purpose, application level, and operational scale, these pillars and levers complement each other.

Our overview also considers the institutional and political complexity that underlies the transition. The adoption of changes in agricultural practices and systems will meet tougher resistance and hindrances at large scales and high decision levels than at individual and local levels. Policy, decision-making, and political, institutional, financial, and collective (from national to global) dimensions should be considered. Gathering political momentum in support of agroecology is key, as was the case during the Green Revolution. The Green Revolution had one main objective, i.e., famine eradication, and had massive political, financial, and institutional support. The agroecological transition, in contrast, has multiple objectives: increasing human access to food and human well-being, increasing biodiversity and resource conservation, and reducing the use of fossil carbon. It requires a similar thrust, with at least similar political and financial support, as the Green Revolution.

An increasing number of global organizations adhere to agroecology principles and the links of those principles to more sustainable and healthier food systems. The current global crises represent a serious opportunity to rethink the way humanity manages its food supply. Our overview presented here is another plea to sustain and reinforce the momentum for agroecological transitions by the diverse farming systems of tropical agriculture.

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Declarations

Ethics approval The authors state that the research described in this article was conducted in accordance with the recommended standard principles of objectivity, transparency, and ethics.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that human research participants provided informed consent for publication.

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