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Agroecology and Systems Analysis for Sustainable Agriculture

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Agroecology and systems analysis have always been associated as at the core of agroecology is the search for synergies through the interactions of different components to support sustainable, resilient and equitable agricultural systems. Several agroecosystems analysis methods and tools have been developed. Systems approaches provide the theoretical basis and practical guidelines to capture the complexity of agroecosystems and design better, more sustainable, systems. These methodologies have been developed by and for different actors along the agricultural research and development continuum, from highly elaborated mathematical models to truly hands-on practical guidelines. Three examples of methodologies are briefly described. The Tool for Agroecology Performance Evaluation (TAPE), a global and collective effort to generate evidence on the extent and role of agroecology for transitioning towards more sustainable agroecosystems. The MESMIS framework, based on the participatory selection of multiple indicators, their quantification and integration for holistic assessment. Finally, FarmDESIGN, a model-based optimization tool allowing to assess current and alternative farm configurations and farming practices and quantify trade-offs, allowing the design of alternative, more sustainable systems. The application and adaptation of these and other systems analysis methods and tools can play a crucial role in the transition towards more sustainable agroecological systems.

Key words: agroecology, indicators, multi-criteria, sustainability, tradeoffs, synergies

1. Introduction

Agroecology is today one of the most promising paradigms for agricultural development. With origins on exploiting the ecological interactions within agricultural systems to improve their efficiency and sustainability; today agroecology is considered a practice, a science and a movement (Wezel et al., 2009).

Agroecosystems are inherently complex systems. Multiple components are in constant interaction resulting in emergent phenomena at different scales in time and space. Moreover, farmers manage agroecosystems to satisfy a multiplicity individual and societ al. goals such as food and nutritional security, income generation, risk management, the preservation of cultural values and environmental stewardship, among many others. In agroecology, the complex and multifunctional nature of agroecosystems is acknowledged, and several efforts have been directed towards the development of methods and tools to capture such complexity and provide elements for the design of more sustainable agroecosystems, or more generally, natural resource management systems.

2. Systems approaches for analysis and design of agroecosystems

Systems approaches provide the theoretical basis and practical guidelines to capture the complexity of agroecosystems and design better, more sustainable, agricultural and natural resources management.

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Several methods and tools have been developed by and for different actors along the agricultural research and development continuum. From highly elaborated mathematical models to truly hands-on practical guidelines, these methods and tools aim at assessing, through multiple criteria, current and alternative agricultural systems.

(1) The TAPE framework. Assessing transition towards agroecological systems

The Tool for Agroecology Performance Evaluation (TAPE) (Mottet et al., 2020) is a global and collective effort, including dozens of representatives of agroecology-related organizations worldwide and led by FAO, to generate and consolidate evidence and assist policy makers and other stakeholders, to put agroecology at work towards sustainable food and agricultural systems and contribute to the sustainable Development Goals (SDG).

TAPE generates data and provide analytical pathways on different development objectives through criteria and indicators derived to represent the different elements of agroecology: diversity, co-creation of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food traditions, responsible governance, and circular and solidarity economy (FAO 2018).

TAPE is applied through consecutive steps: Step 0 is a preliminary step to describe the main socio-economic and demographic characteristics of the agricultural and food systems under analysis and a description of the enabling environment in terms of relevant current and historical policy, market, technology and/or socio-cultural drivers; Step 1 guides the characterization of the agroecological transitions aiming at establishing scores and assessing the degree of transition. In Step 2, core criteria are informed to assess the performance of agroecosystems and finally, in Step 3, a participatory validation of the results carried out with farmers and other relevant stakeholders.

TAPE has been pilot-tested and is currently under application in several case studies around the world to assess the extent of agroecological transitions among agricultural producers in several communities, monitor and evaluate projects by characterizing the initial and subsequent steps in an agroecological transition, and/or evaluate widely diverse agricultural systems against agroecological elements and how they contribute to the achievement of the SDG.

Beyond the generation of evidence on the role of agroecology for the sustainability of agricultural systems, TAPE is also conceived to support the transition of all forms of agricultural systems towards more sustainable practices, and the formulation of adequate policies to enable this transformation towards sustainable agricultural and food systems.

TAPE can also provide a framework for governments and public actors for the adaptation and re-design of research and development programs, as well as rural advisory services and extension programs, to properly address sustainable agriculture in the context of the SDG. Indeed, the information collected by TAPE can be used to inform various SDG indicators, including 2.4.1 (sustainable agriculture), 1.4.2 (land rights) or 8.6.1 (biodiversity).

(2) The MESMIS framework. Participatory multi-criteria assessment

The MESMIS framework is one of the first efforts to apply systems analysis for the evaluation and design of agroecosystems through the use of context specific indicators (Speelman et al., 2007).

Based on a systems approach, MESMIS provides guidelines for the derivation, quantification, and integration of locally relevant indicators. Sustainable systems properties or attributes are the basis for the selection of context specific indicators. These attributes are inherent characteristics of sustainable systems: productivity, stability, adaptability, resilience, reliability, equity, and self-reliance. Strategic indicators, informing these systems properties, are derived mainly through participatory approaches to reflect the objectives of farmers and other stakeholders involved on agricultural development.

The operational application of the MESMIS

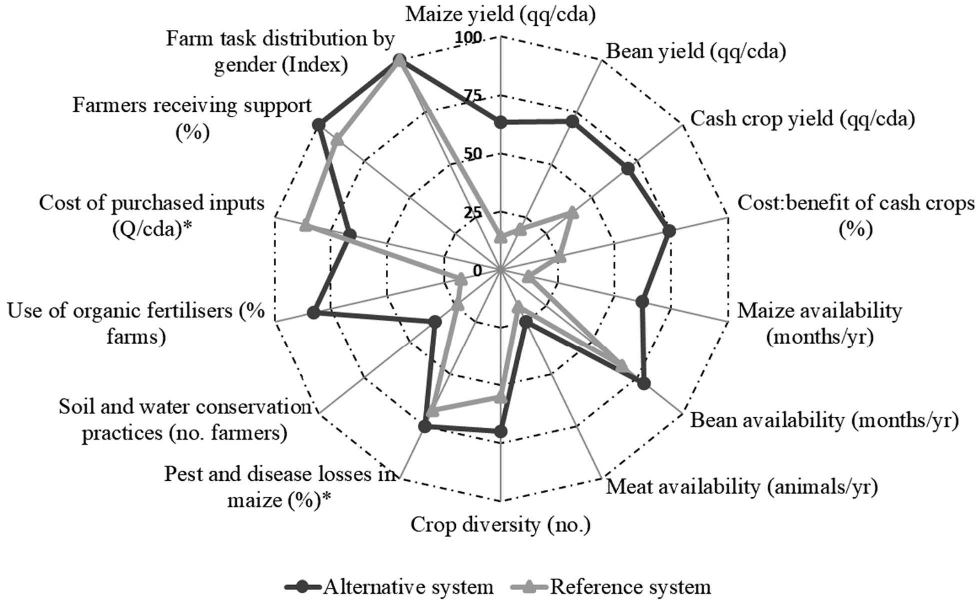

Fig. 1 Multi-criteria assessment of current (reference) and alternative (agroecological) systems in the Western Highlands of Guatemala using the MESMIS methodological framework (adapted from Gonzalez-Esquivel et al., 2021).

framework has a cyclic structure and is divided into six different steps: The first three steps are devoted to the characterization of the systems, the identification of critical points and the selection of specific environmental, social and economic indicators. In the last three steps, indicators are quantified and integrated for whole-systems multi-criteria assessment, and elaborate recommendation to improve their sustainability.

MESMIS has been applied in over 120 case studies with the participation of local development agents, NGO's and university students and researchers. A great diversity of farming systems has been evaluated with MESMIS, ranging from crop and livestock-based systems, forestry, fisheries and ecotourism, and, in most cases, mixed systems where multiple components are interlinked. Figure 1 shows an example of the results from MESMIS application to assess agroecological options in the Western highlands of Guatemala (Gonzalez-Esquivel et al., 2021).

(3) FarmDESIGN. Modelling for analysis and design of agroecosystems

FarmDESIGN is a model-based tool for assessing the performance of agroecosystems and designing alternative, more sustainable systems. In FarmDESIGN, the main flows and stocks within farm systems are quantified (Fig. 2) and a series of economic and environmental indicators calculated (Groot et al., 2012).

Through a multi-objective optimization algorithm, FarmDESIGN generates a large set of pareto-optimal alternative farm configurations. With these model-generated alternative systems, it is possible to identify and quantify main trade-offs and select specific farm systems that satisfy different goals and minimize these trade-offs.

FarmDESIGN has been applied to a wide diversity of systems in all agricultural regions of the world. Although a predominantly research oriented use of FarmDESIGN, it has also been used for practical actions trough participatory analysis and discussion on the main results generated by the model and the

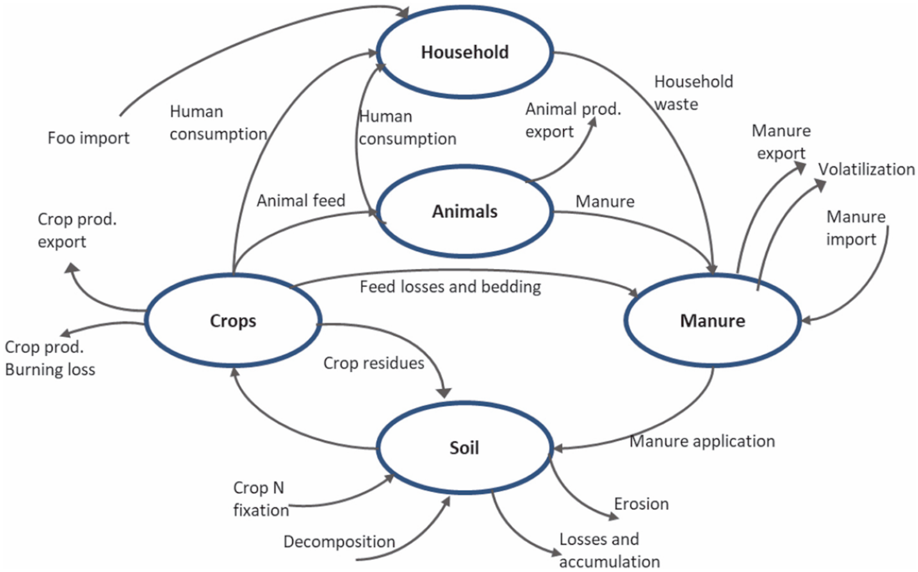

Fig. 2 Main flows and stocks represented in FarmDESIGN (adapted from Groot et al. 2012).

practical options to transition towards more sustainable agroecosystems (Adelhart Toorop et al., 2020)

3. Agroecology and Systems Analysis for Sustainable Agriculture

Farming systems are complex agroecosystems (multi-component, multi-functional) and multicriteria assessments are needed to evaluate their status, the contribution of agroecological principles and practices to their performance, and allow the design of more sustainable systems

Systems theory and tools allow to assess these complex systems. Three examples of tools for systems analysis have been briefly described here. Basic properties of sustainable systems, such as those suggested in MESMIS can be used to derive context specific indicators to assess different socio-technical innovations, similarly TAPE uses the ten elements of agroecology for such selection.

Quantification of indicators for multi-criteria assessment can be based on several methods. Direct measurements, surveys and modelling, among others, can be combined within an analytical framework allowing to adapt the evaluation to the expertise and resources available for specific applications.

Integration of indicators is key for the assessment of agroecosystems allowing a holistic view on their performance, identify the main areas for improvement and detect or characterise potential trade-offs and synergies among objectives and indicators. Some model-based systems analysis tools, such as FarmDESIGN, allow the exploration of plausible farm configurations to improve the performance of agroecosystems and quantify main trade-offs and synergies to identify optimal implementation of agroecological alternatives.

Agroecology, as a practice, a science, and a movement, is based on a systemic approach for agricultural production and rural development. The application and adaptation of several of the frameworks, methods, and tools available for systems analysis can provide the necessary guidelines for the transition towards more sustainable systems based on agroecological principles.

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