Agroecological approaches to sustainable agriculture and rural development: A mini review

Comment [SAS1]: The title is not fully align with the manuscript

Abstract

Comment [SAS2]: Overhaul the abstract by establishing a linkage between agro ecology and its Importance to sustainable agriculture and rural development.

Agroecology is an academic discipline that studies ecological processes applied to agricultural production systems. It is a multidisciplinary science encompassing fields such as social, economic, ecology, and environment. Agroecology is founded on the principle of the sustainable use of resources and employs various approaches to address current challenges in agricultural production. Initially focused primarily on crop production and protection, in recent decades, it has expanded to include new dimensions such as environmental, social, ecological, economic, and agro-political issues. The discipline embraces three main approaches: investigations at plot and field scales, investigations at the agroecosystem and farm scales, and investigations covering the entire food system. This paper provides an extensive literature review of concepts, definitions, and principles of agroecology, with a primary focus on the relationship between agroecological approaches and sustainable agriculture and rural development.

Keywords: Agroecology; Sustainable agriculture; Agroecological principles; Ecological political economy; Agro-population ecology; Integrated assessment of agricultural systems

1 Introduction

Comment [SAS3]: In Introduction there should be a linkage with the title. However, there is no cholonological linkage between agro ecology & sustainable agriculture. Authors need to depict why different agro ecological approaches are essential for sustainable agriculture and rural development.

Here, the introduction is mostly confined to definitions of agro ecology.

Agroecology is the study of the interaction between plants, animals, humans, and the environment within agricultural systems (Dalgaard et al., 2003). It serves as the scientific foundation for cultivating food, fuel, fiber, and other land-raised products in harmony with nature and natural processes (Figure 1) (Wojtkowski, 2012). The term 'agroecology' was originally coined by Bensin (1928, 1930) in two scientific articles, and later by Gliessman (2007) and Warner (2007) in novels (A. Wezel et al., 2009). Despite its introduction in 1930, there has been considerable confusion over the course of 80 years of history (A. Wezel et al., 2009). Over the past three decades, influenced by visionary farmers, academics have increasingly applied ecological insights to agricultural systems, leading to the emergence of a multidisciplinary discipline known as agroecology (Tomich et al., 2011). Agroecology is a term that can denote a scientific discipline, an agricultural technique, or a political and social movement (Dalgaard et al., 2003). Scientifically, Gliessman defines agroecology as "the science of applying ecological concepts and principles to the design and management of sustainable food systems," highlighting its roots in agronomy and ecology (Tomich et al., 2011).

Its recognition as a distinct scientific discipline aligns with Robert King Merton's criteria for science in 1973 (Dalgaard et al., 2003). Agroecology is characterized as an integrative discipline incorporating elements from agronomy, ecology, sociology, and economics, evident in its historical development, current structure, and future objectives (Dalgaard et al., 2003).The prevalent definition of agroecology in the contemporary context revolves around applying ecological concepts and principles to develop and manage sustainable agroecosystems, essentially constituting the science of sustainable agriculture (S. Gliessman, 2018). The term itself originated from a movement striving to advance sustainable agriculture by integrating ideas and methods from diverse disciplines. Initially rooted in crop physiology, agricultural zoology, and ecology, it evolved into a comprehensive discipline covering integrative studies within agronomy, ecology, sociology, and economics (Dalgaard et al., 2003).

While originally centered on crop production and protection, agroecology has expanded its scope to encompass various aspects such as environmental, social, economic, ethical, and developmental challenges that have emerged in recent decades (A. Wezel et al., 2009). Consequently, agroecology is characterized as a discipline involving integrative studies within agronomy, ecology, sociology, and economics (Dalgaard et al., 2003). The scalability of agroecology is contingent on practitioners having access to detailed knowledge of local conditions and employing appropriate agricultural strategies. The core principle of agroecology lies in designing fully functional and sustainable ecosystems for food crops, modeled on natural systems (Raghavan et al., 2016).

In essence, the current definition of agroecology underscores its role as the integration of study, education, action, research, and change to promote ecological, economic, and social sustainability across all facets of the food system (S. Gliessman, 2018). It is transdisciplinary, considering diverse forms of knowledge and experience in transforming the food system. The participatory nature of agroecology emphasizes the involvement of stakeholders at every stage, from farm to table and everyone in between. Furthermore, it is action-oriented, challenging the economic and political power structures of the current industrial food system with alternative social structures and policy actions (S. Gliessman, 2018). The method is grounded in ecological thinking, requiring a holistic, systems-level understanding of food system sustainability.

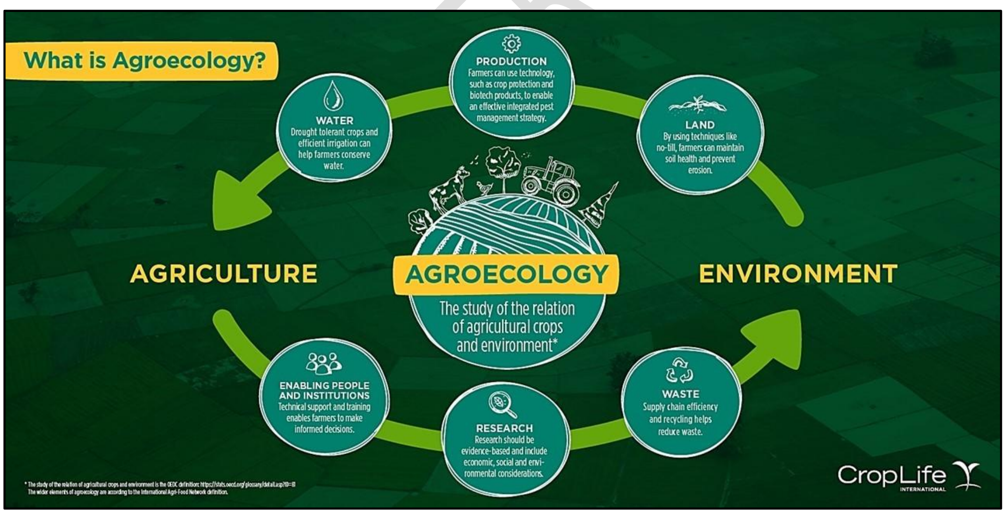

Figure 1: Sustainable and Innovative Agricultural Systems In-focus: Agroecology (Modified from Devereux, 2021).

2 Agroecological principles to SARD

The principles of agroecology for Sustainable Agriculture and Rural Development (SARD), as elucidated by Alexander Wezel et al. (2020) and Rajbhadari (2015), encompass a holistic and integrated approach to agricultural practices (Figure 2). One fundamental principle involves ensuring farmers' access to essential resources and capital while concurrently empowering and mobilizing communities to actively engage in sustainable agricultural practices. By prioritizing access to resources, this principle aims to enhance the capacity of farmers and communities to adopt and sustain environmentally conscious farming methods. Another vital aspect of agroecological principles is the conscientious use of renewable resources. This entails the utilization of bio-organic fertilizers, green manure, farmyard manure (FYM) (Adhikari et al., 2023), and biopesticides/botanical pesticides (Yadav et al., 2022a; Yadav et al., 2022b). The emphasis on renewable resources aligns with the overarching goal of sustainable resource management, promoting practices that contribute to long-term environmental and agricultural viability. Resource conservation is a key tenet of agroecology, urging the implementation of practices that safeguard vital elements such as soil, water, energy, and genetic resources. This principle underscores the importance of responsible resource stewardship to mitigate environmental degradation and promote the resilience of agricultural systems. Agroecology also emphasizes the conservation and judicious use of biodiversity, spanning landscapes, biota, and cultural diversity. Prioritizing health, the principles advocate for the well-being of humans, animals, soil, plants, the environment, and cultural aspects, fostering a balanced and sustainable coexistence between agriculture and ecosystems. To minimize environmental and health risks, agroecological principles advocate for the reduction of toxic substances, advocating the elimination of materials like chemical pesticides (Karki et al., 2023), herbicides, and chemical fertilizers. Managing ecological relationships involves fostering productive interactions among plants, animals, soils, and the biosphere, enhancing ecological balance within agricultural systems. A holistic perspective is encouraged through the management of whole systems, considering landscapes, households, farms, communities, and ecological or bio-regions. Finally, the principles strive to optimize long-term benefits, focusing on intergenerational benefits, livelihoods, quality of life, and the overall sustainability of agricultural practices. In conclusion, the principles of agroecology represent a paradigm shift towards a comprehensive and sustainable approach to agriculture. Their implementation is designed to foster resilient, equitable, and environmentally conscious agricultural systems, thereby contributing to sustainable rural development.

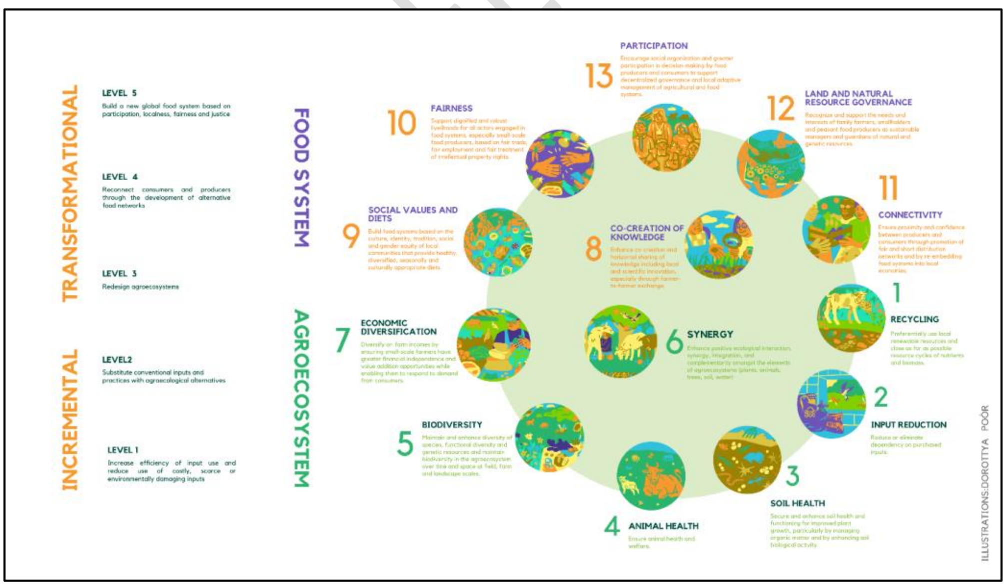

Figure 2: Principles of agroecology and the levels of transition towards sustainable agriculture and rural development (Modified from Agroecology Europe, 2022).

3 Agroecological approaches on SARD

The various agroecological approaches related to Sustainable Agriculture and Rural Development, as highlighted by Rajbhadari (2015) and Mason et al. (2021), encompass a range of strategies aimed at promoting ecological sustainability, social equity, and economic viability in agricultural systems. Here are the identified agroecological approaches:

3.1 Ecosystems agroecology

The foundation of comprehending the sustainability of agroecosystems lies in natural ecosystems and traditional, also known as local or indigenous, agroecosystems (Gliessman, 2016). Natural ecosystems function as templates, providing insights into the ecological fundamentals crucial for the enduring viability of a specific region (Gliessman, 2016). Over time, traditional agroecosystems have undergone transformations, serving as illustrative examples of how cultures and their surrounding environments adapt through processes that harmonize people's needs with ecological, technological, and socioeconomic factors (Gliessman, 2016). The amalgamation of this understanding with insights into societal change has elevated the science of agroecology into a powerful instrument for reforming food systems. Natural ecosystems, crafted through prolonged adaptation to local ecological conditions and the utilization of indigenous resources, yield valuable lessons for sustainable agricultural practices. The distinction of traditional and indigenous agroecosystems from conventional systems lies in their evolution in periods or regions where inputs beyond human labor and local resources were either unavailable or undesirable (Gliessman, 2016). Given that agriculture represents the primary nexus between humans and the environment, the imperative to strike a balance between crop output and environmental integrity, encapsulated in the concept of sustainable crop production, stands out as a critical challenge for agriculture and forthcoming generations of farmers (Yadav et al., 2023a). This challenge underscores the necessity of integrating ecological principles, local knowledge, and sustainable practices in agriculture to ensure the well-being of both the environment and the communities it sustains (Yadav et al., 2023b).

The ecological services provided by soil biota play a crucial role in determining soil quality, plant health, and soil resilience (Gianinazzi et al., 2010; Yadav et al., 2023c). Particularly, soil microorganisms forming mutually beneficial connections with plant roots have garnered increased attention in agricultural research due to their potential to enhance plant growth and reduce inputs in sustainable cropping systems (Gianinazzi et al., 2010). However, human management of agroecosystems, impacting natural ecosystem structures and processes, poses challenges in their analysis compared to natural ecosystems (Gliessman, 2016). While agriculture and ecosystem services are essential for human survival and quality of life, current agricultural practices aimed at boosting global food supply have unintentionally resulted in negative consequences for the environment and ecosystem services (Gianinazzi et al., 2010). The foundational concept of the ecosystem, characterized as a functional system of interconnected relationships between living organisms and their environment, is a cornerstone of agroecology (Gliessman, 2016). When humans manipulate an environment to establish agricultural output, they create an agroecosystem, and understanding these systems requires an ecological perspective. Computational agroecology emerges as a tool to convert various types of land into new food-producing ecosystems aligned with local conditions and long-term ecological health and food security (Raghavan et al., 2016). In contrast to a well-developed natural ecosystem that is stable, self-sustaining, and adaptable to change, agroecosystems undergo manipulation for human purposes and require sustainable management practices. Agroecology provides a comprehensive ecological framework for understanding the structure, function, linkages, and dynamics of agroecosystems at various levels, from individual plants or animals to farms, regions, and the global food chain (Gliessman, 2016; Gliessman, 2013). In-depth examinations of the ecological effects of cultivation, grazing, irrigation, and fertilization on the soil ecosystem are essential. Solutions are recommended to maintain a healthy, productive soil and crop ecosystem, considering negative effects of pesticides and proposing alternatives such as biological control, crop rotation and diversity, sanitation, and innovative chemical attractants and technology, deterrents (Yadav et al., 2022c; Yadav et al., 2022d), and plant resistance (Yadav et al., 2023d; Sharma et al., 2022). The symbiotic relationship between arbuscularmycorrhizal (AM) fungi and plant roots is highlighted for its role in enhancing plant nutrient uptake and providing non-nutritional benefits such as soil stabilization, erosion prevention, and alleviation of plant stress caused by various factors (Gianinazzi et al., 2010).

3.2 Ecological political economy

Ecological political economy, a multidisciplinary field primarily led by human geographers, offers a comprehensive perspective on various environmental challenges through a socio-ecological lens (Craig & Hay, 2017). This field, rooted in a political-economic critique of industrial agriculture, draws extensively from the social sciences, presenting a critical view of the prevailing capitalist economy that freely exploits resources and waste-sinks (Mason et al., 2021). Central to ecological political economy is the concept of commodification theory, where theories generally assume a capitalist system that commodifies resources without adequate consideration for environmental consequences (Quastel, 2016). It has evolved as a practical response to the environmental and social repercussions arising from industrial agriculture, reflecting a commitment to address and mitigate these impacts (Mason et al., 2021). The idea of "political agroecology," as emphasized by Gonzalez de Molina in 2013, underscores the need to establish institutions, policies, and social momentum to facilitate the agroecological transition (Mason et al., 2021). This approach acknowledges the role of politics and governance in shaping agricultural practices and environmental outcomes. Optimists within the ecological political economy envision a new era of capitalist prosperity as an opportunity for progressive political forces to build more stable, inclusive, and just political economies compared to those that followed the crises of the 1970s (Craig & Hay, 2017). The belief is that by leveraging this period of economic growth, there is potential to address environmental and social challenges more effectively. For agroecological science to contribute meaningfully to a transition toward environmental, economic, and social sustainability, it must move beyond simplification (Mason et al., 2021). This suggests a need for a nuanced understanding of the complex interactions within agroecosystems and the broader socio-economic context, recognizing the intricate relationships between ecological processes and political-economic structures.

Agriculture faces a triad of interconnected challenges: meeting the escalating demand for food security in a continually growing global population, adapting to the impacts of climate change, and mitigating climate change without compromising production (Raseduzzaman.M, 2016; Katel et al., 2023a). To effectively catalyze a transition to environmental, economic, and social sustainability, agroecological science needs to progress beyond merely investigating farming concepts and methods that balance productivity and environmental considerations (Mason et al., 2021).The term "ecological political economy" (EPE) is chosen over the alternative "environmental political economy" due to its superior descriptive precision (Craig & Hay, 2017). EPE underscores capitalism as a system characterized by widespread commoditization of labor and production, fossil fuel-based industrialization, and technical innovation oriented toward continuous monetary profit expansion (Quastel, 2016). Linking the state to the demands of capital, EPE delves into a range of political economy issues by highlighting the unequal distribution of power among people and animals, considering economic, political, and ecological

Comment [SAS4]: Author should more elaborately depict with references how sustainable agriculture and rural development will be ensured by adopting ecological political economy approach dynamics as outcomes of this power imbalance (Craig & Hay, 2017). Crucially, ecological political economy necessitates a transition theory that elucidates the pathway from the present state to more desirable futures (Quastel, 2016). Establishing its significance in the broader realm of political ecology, work grounded in EPE contributes uniquely to understanding and addressing environmental challenges within the context of political-economic structures. Capitalism, with its inherent contradictions and reliance on finite resources, energy, and waste sinks on a finite planet, is a central focus of ecological political economy (Quastel, 2016). Activists and social movements increasingly link environmental crises with capitalism, signaling a growing awareness of the intertwined nature of ecological and economic issues (Quastel, 2016). In contrast, various political economy literatures, committed to the contextualized study of modern political-economic change, emphasize the connection between nature, class relations, and capital accumulation (Craig & Hay, 2017). This underscores the importance of understanding how ecological considerations intersect with broader socio-economic dynamics.

3.3 Agro-population economy

Comment [SAS5]: Author should more elaborately depict with references how sustainable agriculture and rural development will be ensured by adopting Agro-population approach

Agronomic agroecology, significantly influenced by agronomy, has emerged as a practical field responding to the environmental and social consequences of industrial agriculture (Mason et al., 2021). In light of three interconnected challenges—meeting the demands of a growing global population for increased productivity and revenue to ensure food security, adapting to the impacts of climate change, and mitigating climate change without compromising production (Raseduzzaman.M, 2016)—agroecological science faces the critical task of transcending traditional research on farming concepts and methods. The aim is to strike a balance between productivity and environmental considerations, facilitating a seamless transition toward environmental, economic, and social sustainability (Mason et al., 2021). Katel et al. (2023b) shed light on the significant role played by crop import and consumption patterns in a country's food system. They emphasize the importance of understanding these patterns as a key component in addressing the challenges posed by a changing climate. Notably, various management-level adaptation options for agricultural systems have been proposed to tackle anticipated climate change impacts. Among these options are strategies such as soil organic matter management and the application of technologies for water collection and soil moisture retention. Adjustments in planting dates, particularly for spring crops, are also considered under climate change scenarios (Diacono et al., 2017). Implementing proper rotations, introducing agro-ecological service crops (ASC) as buffer zones or break crops, adopting reduced tillage practices, and managing fertilization can provide valuable services to agro-ecosystems (Yadav et al., 2022e). These practices contribute to weed, pest, and disease management, reduce NO3 leaching, and enhance crop tolerance to drought in low-input and organic farming systems (Diacono et al., 2017). Efficient energy use by the agricultural sector is identified as a criterion for sustainable agriculture, providing financial savings, preserving fossil resources, and reducing air pollution (Diacono et al., 2017). This underscores the importance of aligning agricultural practices with sustainability goals and optimizing resource utilization for long-term environmental and economic benefits.

3.4 Agro-population ecology

Comment [SAS6]: Author should more elaborately depict with references how sustainable agriculture and rural development will be ensured by adopting Agro-population ecology approach

Agro-population ecology is a scientific discipline situated at the intersection of agriculture and ecology, drawing on principles from natural science. It explores the dynamics of agricultural populations, considering various ecological perspectives to understand the relationships between organisms, their environment, and the sustainability of farming systems (Mason et al., 2021).

4 Integrated assessment of multifunctional agricultural systems

The integrated assessment of agricultural systems demands a comprehensive consideration of various roles, involving the quantification and integration of economic, social, and environmental variables associated with these systems' performance (Sylvestre et al., 2013). Achieving objectives aligned with sustainable development relies on the adoption of innovative agro technologies, the (re-)design of agricultural systems, and the implementation of policies related to agriculture, environment, and rural development across different hierarchical levels (M. K. Van Ittersum&Wery, 2007). To calculate multiple indicators effectively, a multi-criteria analysis and the integration of knowledge from diverse fields, including economics, agronomy, ecology, and social sciences, are essential. This integration spans knowledge derived from scientific research and local wisdom (Sylvestre et al., 2013). Process-based understanding of agro-ecological relationships is crucial for evaluating the performance of agricultural systems and their contributions to sustainable development. However, this assessment needs to strike a balance, offering a certain level of detail while being tailored for seamless integration with other factors and systems (M. K. Van Ittersum&Wery, 2007). Integrated assessment, a relatively recent addition to agronomic studies, has gained prominence, with research recommending the adoption of integrated assessment and modeling (IAM) as a means to enhance the management of intricate environmental systems (M. Van Ittersum et al., 2006). Policies in agriculture, environment, and rural development are urged to align with these goals in a cost-effective and efficient manner, emphasizing the need for a holistic and integrated approach (M. Van Ittersum et al., 2006).

The assessment of agricultural systems must encompass their contributions to long-term development, requiring an integrated evaluation of their performance across economic, social, and environmental dimensions at various scales, ranging from the field to the regional level (Sylvestre et al., 2013). Model-based methods play a key role in translating agronomic knowledge into integrated research. Two commonly encountered methods in literature involve dynamic crop or cropping system models with varying levels of complexity and the generation and utilization of input-output coefficients for agricultural activities (M. K. Van Ittersum&Wery, 2007). Integrated Assessment Modeling (IAM) is characterized as an interdisciplinary and participatory process that combines, interprets, and communicates knowledge from diverse scientific disciplines, fostering a better understanding of complex phenomena (M. Van Ittersum et al., 2006). Agricultural systems worldwide are in a state of constant flux due to factors such as expanding trade blocs, globalization, liberalization, the adoption of novel agro-technologies, evolving societal needs, and the impacts of climate change (M. Van Ittersum et al., 2006).

5 Conclusion

Agro-ecology emerges as a comprehensive multidisciplinary field, delving into a range of ecological processes with a primary focus on the intricate interplay between the environment and agricultural systems. Rooted in the principles of sustainable agriculture, it champions the use of renewable resources, advocates for the preservation of nature and the environment, and encourages the adoption of organic farming practices. The influence of social, ecosystemic, and political ecology stands prominently, shaping and influencing the nuanced processes within the realm of agro-ecology.

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