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Agroecology integrates science, practice, movement, and future food systems

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Abstract. Agroecology is an interdisciplinary field that brings together agricultural practice and ecological principles. This article explores agroecology's theoretical foundations, practical applications, and historical evolution, along with its impact on modern agricultural methods. Agroecology looks at how biophysical and social elements combine to produce food sustainably, promote social justice, and protect the environment. The first section of the article looks at how agroecology developed as a scientific field, discussing its fundamental ideas, practices, and objectives- all of which emphasize participatory, adaptive, and holistic methodologies. The inquiry also looks into how agroecology might support biodiversity, resilience to climate change, and sustainable livelihoods. This article also explores the rise of agroecology as a movement driven by social activism, environmental consciousness, and a search for alternative food systems. After that, the article dives further into the history of agroecology, emphasizing the pioneers' contributions and the development of agroecological principles over time. The text goes on to outline the fundamental principles of agroecology. Its main objectives are enhancing resource efficiency, strengthening resilience, and ensuring social equality. This article discusses the practical applications of agroecology in various agricultural settings, such as permaculture, agroforestry, and agroecological farming systems. A few agro-ecology case studies have been described. Finally, the article highlights the future of food systems. The article concludes by highlighting the necessity of combining scientific understanding with indigenous ecological and cultural knowledge and stating that agro-ecology is viable for a more just and sustainable future for agriculture and food security.

Keywords: *Farming, permaculture, regenerative agriculture, social equity, and sustainable food system*

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1. Introduction

1.1. Definition and elucidation of agroecology as a scientific discipline and social movement

Agroecology, which refers to the study of farming and food systems from an ecological perspective, has gained traction since the 2000s as a crucial concept for addressing pressing global challenges. These challenges include significant biodiversity decline, food insecurity, inadequate agricultural resilience to climate change, and insufficient livelihood security for farmers (Altieri, 2002; Wezel et al., 2009; Rosset et al., 2019). Agroecology encompasses the environmental, social, and economic aspects of food systems through a comprehensive and linked approach that recognizes their complexity and interdependence. Agroecology seeks to strengthen the connections between many stakeholders (such as farmers, producers, researchers, and consumers) and between diverse fields of study (such as ecology, agronomy, social sciences, and economics) through its transdisciplinary, participatory, and action-oriented approach.

Agroecology is the scientific examination of the interrelationships among plants, animals, humans, and the environment within agricultural systems. Agroecology is an interdisciplinary field that encompasses the study of agronomy, ecology, sociology, and economics (Dalgaard et al., 2003). According to Altieri & Koohafkan (2008), agroecology is the field of study that offers fundamental ecological principles for examining, planning, and overseeing agroecosystems that are productive, conserve natural resources, and are culturally sensitive, socially equitable, and economically sustainable.

The term "agroecology" is increasingly being used, and its definitions are changing (Figure 1). In addition to being used to refer to the scientific field of agroecology, the phrase can also refer to a movement or method of farming. In the 1960s, environmental groups frequently emerged in opposition to industrialized agriculture, which occurred when state policies ignored the social dimensions of rural development and the environmental impact of agriculture, particularly pesticides. At first, the movement was not explicitly named with the term "agroecology." Only in the 1990s did the phrase begin to be used in this sense, particularly in the USA and Latin America, to express a new perspective on agriculture and its role in society. At the same time, a third usage emerged for designing a set of agricultural practices. Agro-ecological practices are typically viewed as novel, repurposed, or modified methods or strategies within organic or alternative agriculture, traditional agriculture in underdeveloped nations, or more ecologically friendly agriculture (Wezel & Soldat, 2009).

Wezel et al. (2009) define agroecology as encompassing three aspects: a scientific field, a social movement, and a collection of practices. These three characteristics have varying degrees of importance depending on the context: in France, there is a heavy emphasis on the practice; in Germany, the scientific discipline is prioritized; and in Brazil, the focus is on the social movement. It is necessary to develop all three dimensions- social, technical, and environmental- in a coordinated manner, particularly to promote a comprehensive, interconnected approach that has the ability to transform existing agricultural models and facilitate the transition towards more sustainable food systems (van der Ploeg et al., 2019). The triple interpretation is also evident in the practical aspects of decision-making processes in agriculture within the knowledge society. These aspects include: (1) assessment, which involves science and knowledge; (2) management, which encompasses institutions/governance, social systems, and legislation; and (3) practices, which are related to production (including technologies), distribution, and markets. These aspects are intricately linked and cannot be disentangled, mirroring a narrative or cognitive framework. Agricultural practices are assessed and modified to give management with valuable information, which in turn influences agricultural practices (Rivera-Ferre, 2018).

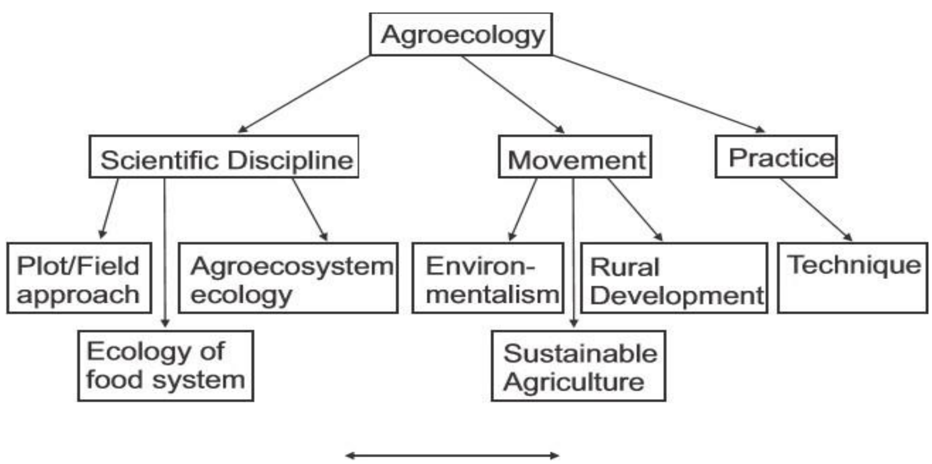

Figure 1. Agro ecology as a science, a movement and a practice (Wezel et al., 2009)

1.1.1. Agroecology as a science

The word agroecology emerged in European and US scientific literature around the late 1920s, as researchers began integrating ideas from ecology and agronomy to get a deeper understanding of diverse agricultural systems (Sachet et al., 2021). Scientists have regarded the field and the farm as "domesticated ecosystems" and have directed their attention on studying the relationships between plants, animals, soils, and climate. Their goal is to gain knowledge about various aspects such as nutrient cycle, biodiversity, and energy efficiency in crop production. The science of agro ecology initially concentrated on the environmental implications of different production systems at the scale of the field or the farm. This remains mostly true in certain circumstances, such as Germany and certain portions of Europe. However, in other regions, particularly the Americas, the academic comprehension of agroecology has expanded to encompass the ecological aspects of the entire food chain (van der

Ploeg et al., 2019). Contemporary scholars do no longer accept solely scientific or technical interpretations of agroecology. Instead, they advocate for a transdisciplinary, participatory, action-oriented approach that integrates knowledge from natural, environmental, and social sciences (Carlile & Garnett, 2021).

1.1.2. Agroecology as a practice

In response to concerns raised by Rachel Carson's book Silent Spring regarding the impact of agriculture on wildlife and the environment, a set of agroecological practices emerged. These practices aimed to shift away from the dominant model of industrial agriculture, which relied heavily on large-scale specialized farms, fossil fuels, and external artificial inputs. Instead, the focus was on developing more environmentally friendly and sustainable agricultural systems that optimize the use of biological processes and ecosystem functions (Altieri, 2002; Holt-Giménez & Altieri, 2013). There is no universally established set of techniques that are specifically designated as agroecological. Practices can be categorized as more or less agroecological based on their reliance on ecological processes rather than external inputs. These practices should also be fair, environmentally friendly, locally suited, and owned by the community. Additionally, they should be integrated within a systems approach rather than focusing on individual measures (Trabelsi et al., 2016). Agroecological farming prioritizes the use of various techniques such as diversification, mixed cultivation, intercropping, cultivar mixtures, habitat management for crop-associated biodiversity, biological pest control, enhancement of soil structure and health, biological nitrogen fixation, and the reuse of nutrients, energy, and waste as inputs in the production process. Certain practices mentioned in the text have been implemented to different degrees in various regions throughout the world for many years, while others have been more recently created but have not been widely adopted yet (Wezel et al., 2009; Sinclair et al., 2019).

1.1.3. Agroecology as a social movement

In the 1980s and 1990s, various farmer organizations, academics, and NGOs advocating for agroecology joined forces to oppose structural adjustment policies and neoliberalism. They also started integrating agroecology with political activism focused on trade and agriculture policies, both nationally and globally. Consequently, agroecology grew linked to wider collaborative endeavors for transformation and took the shape of a politically active agroecology movement (Rosset et al., 2011). Agroecology, primarily in Latin America, is regarded as a social movement aimed at converting agriculture from an industrial and large-scale exploitation, heavily reliant on fossil fuels and external resources, to a more sustainable approach that relies on human ingenuity and renewable resources within the farm itself. Miguel Altieri, a co-founder of the Latin American Scientific Society of Agroecology (SOCLA), has played a crucial role in this movement. He is an influential author who has effectively connected scientific knowledge with practical applications and has coordinated movements in the field of sustainable agriculture (Altieri & Koohafkan, 2008). Via Campesina is the international promoter of this movement. This organization disseminates information about the effectiveness of small-scale agriculture and advocates for the social rights of peasants to own land and achieve food sovereignty. Brazil has played a leading role in promoting grassroots initiatives led by small-scale farmers. José Lutzenberger, an early supporter, served as the Special Secretary for the Environment to the President of Brazil from 1990 to 1992 (Rivera-Núñez et al., 2020).The comprehensive definition of agroecology encompasses its role as a scientific discipline, practical application, and social movement, which caters to the diverse interests and requirements of various stakeholders such as farmers, agronomists, scientists, social movements, and civil society groups involved in its advancement. Interest in agroecology can be driven by various motivations, such as the aspiration to revolutionize the global food system and tackle global inequalities, the aim to revive and exchange traditional and indigenous knowledge, the need to ensure the economic sustainability of small-scale farming, the goal to enhance household nutrition, the concern about the environmental impact of industrial agriculture, the effort to preserve on-farm natural resources, or the intention to study and optimize interactions within agroecosystems (Carlile & Garnett, 2021).

1.2. Importance and relevance of agroecology in the context of sustainable agriculture

In the 1960s, the Green Revolution achieved significant success as a result of consecutive abundant harvests in wheat and rice. Nevertheless, in the 1980s, the negative consequences of these practices became apparent. A significant increase in cancer cases resulting from excessive exposure to fertilizers and pesticides was observed, and there was a rapid depletion of groundwater due to excessive extraction. This issue became a pressing concern that required immediate action (Herrera et al., 2017). The excessive utilization of chemical fertilizers and pesticides has led to the emergence of soil erosion and salinization, causing significant hardships for farmers. Small and marginal farmers in low-income nations had a widespread occurrence of poverty and debt. In addition to these ailments, the overutilization of pesticides and chemical fertilizers has also resulted in the development of resistance among various weeds and pests, leading to significant crop losses (Gliessman, 2013).

The Green Revolution implemented widespread industrial agriculture on a worldwide scale, while marginalizing small-scale traditional farming. Making commercial use of agriculture and crop production resulted in substantial revenues for foreign firms such as Monsanto. The transition from traditional agriculture to industrial agriculture involved a shift towards prioritizing the production of specific crops such as wheat and rice, with the aim of achieving food security. A move to intensive, chemical-dependent agriculture progressively forced numerous marginal and subsistence farmers into dire impoverishment and indebtedness (Elser, 2012; Holt-Giménez & Altieri, 2013).

Conversely, sustainable farming offers a comprehensive answer to the issues of increasing hunger, malnutrition, unemployment, and environmental damage. Implementing sustainable farming methods has the potential to address the problems generated by industrial farming and facilitate the reintegration of small and marginalized farmers who were compelled to forsake their agricultural occupations. Sustainable farming typically relies on on-site resources and use traditional management approaches instead of relying on purchased fertilizers and pesticides. Implementing this strategy can greatly decrease manufacturing expenses. In addition, sustainable farming relies on human labor and livestock resources rather than expensive machinery and advanced technologies, hence increasing its feasibility for small-scale and economically disadvantaged farmers (Trabelsi et al., 2016; Kerr et al., 2021). Table 1 provides a concise overview of the contrast between Sustainable Farming and industrial Farming.

Table 1. Sustainable farming vs. industrial farming

	Sustainable Farming	Industrial Farming
Cost of Production:	Overall low	Overall high
1. Land	More or less equal	More or less equal
2. Fertilizers	No use of fertilizers	Use of harmful chemical fertilizers
3. Pesticides	Minimal or no use of pesticides	Use of chemical pesticides
4. Seeds	Marginally expensive, but forms a minor portion of the total cost of production	Relatively cheaper
5. Labor	High requirement of labor	Mechanized farming, hence, labor requirement is low
Productivity	Relatively high or equal over a period of time	Declines over a period of time
Income to the Farmers	Lesser cost of production, therefore, net income relatively higher	High cost of production and lesser income generation
Prices for the Consumers	Tends to be relatively expensive	Cheaper, but associated health problems and environmental degradation can raise the overall cost of living

Source: (George & Jafri, 2014)

2. Historical development of agroecology

The fundamental concept of agroecology is that agroecosystems must resemble natural ecosystems in terms of biodiversity and overall functioning. Similar to their natural counterparts, these agricultural mimics have the potential to be fruitful, resistant to pests, and nutrient-efficient (Pimbert, 2015). Agroecology is an applied science that emphasizes both theoretical concepts and practical applications to guide the development and implementation of solutions for real-world challenges. Agroecology facilitates the establishment of shared understanding and rationalization to validate and support managerial actions and decision-making in agriculture and society. Agroecology can be understood as the fundamental connection between ecological theory and the practical application of agriculture. It plays a significant role in the progression of agriculture, as outlined by Caporali (2015), through a series of interconnected words.

Ecology (science) → Agriculture (practice, what is) → Agroecology (applied science) → Sustainable Agriculture (potential practice, what should be) → Organic Agriculture (niche practice, a response to what should be).

This sequence demonstrates how the field of ecology, when applied to agriculture (agroecology), has produced a collection of principles or models for an optimal form of sustainable agriculture (sustainable agriculture) that is presently being put into practice (organic farming) in accordance with a concrete framework (standards) established and endorsed by legislation (Prost et al., 2023).

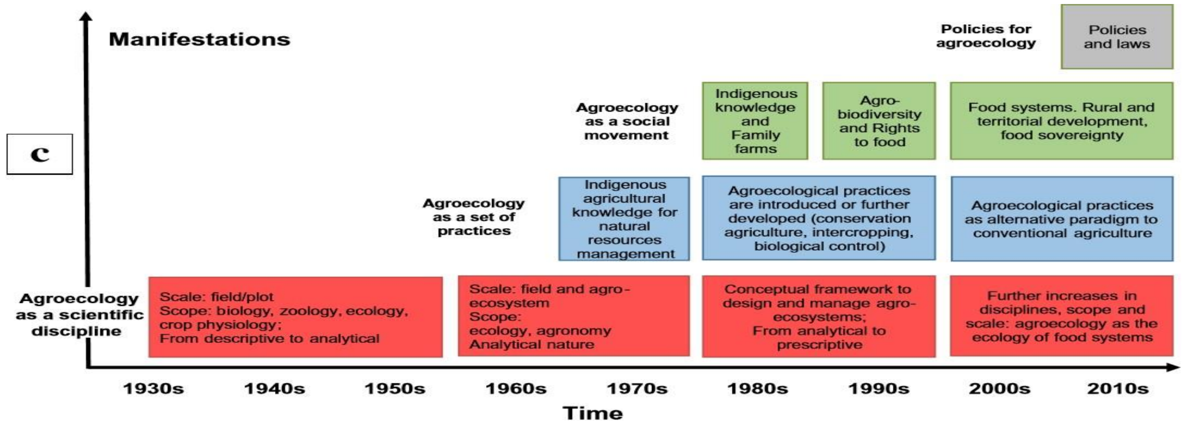

Figure 2. Historical aspects showing the emergence of the three manifestations of agroecology (science, practice, and social movement) with key topics, nature, and scope of research (Wezel et al., 2020)

2.1. Initial phase: 1930s–1960s

Bensin (1925) is credited with coining the word "agroecology" and starting the field's history. As per Gelats (2003), Bensin is credited with tracing the origin of the term agroecology back to the Czechoslovak Botanical Society in 1928. Bensin (1930) proposed the term agroecology to refer to applying ecological techniques to commercial agricultural plants. Thus, applying ecology in agriculture would serve as a preliminary definition for agroecology. A few years later, Bensin (1938) discussed agroecology as a foundational agricultural science. Tischler (1950) was a German zoologist and ecologist who wrote several publications in the 1950s. In these publications, he reported the findings of his agro-ecological research— specifically, on pest management. He also addressed open issues related to soil biology, interactions between insects and plants, and plant protection in agricultural landscapes, including uncultivated environments like hedgerows. Published in 1965, his book was most likely the first to use the term "agroecology" (Tischler, 1965). He examined the many agro-ecological elements (soils, plants, animals, and climate) and how they interact in an agro-ecosystem. He also looked at how human agricultural management affects these elements. With this method, agronomy— the integration of agricultural management— and ecology— the interactions between biological elements at the field level, or agroecosystem— were merged. Additional works in the 1950s and 1960s included field crops (Vavilov, 1957), biology, and pest management (Heydemann, 1953). 7 More agro-ecological publications appeared between the 1930s and the 1960s.

The German biologist Friederichs wrote the first book on agricultural zoology and related ecological and environmental aspects of plant preservation, initially published in 1930 (Friederichs, 1930). The economic cost of pest damage was also assessed, and several pest management techniques were offered, including biological control and the use of natural ecosystems. His strategy closely resembled Tischler's. In 1942, American agronomist Klages produced a second significant work that addressed crop plant distribution from a physiological perspective (Klages, 1942). He also examined the historical, technological, socioeconomic, and ecological aspects influencing their production. Furthermore, although not utilizing the term precisely, Klages (1928) is among the earliest articles addressing agroecology. Although similar to Bensin's definition, the French agronomic Hénin (1967) defined agronomy as "an ecology applied to plant production and agricultural land management" at the end of the 1960s without explicitly adopting agroecology.

An analogous statement can be made for the Italian writer Azzi (1956), who described agricultural ecology as the study of the physical properties of the soil, climate, and environment in connection to the growth of agricultural plants. Thirty years prior, in 1928, the groundwork for his work had already been established. Further information regarding the early stages of the history of agroecology and its origins prior to 1928 may be found in Wezel & Soldat (2009). This first phase in the history of agroecology concerned only agroecology as a science (Figure 2). Subsequent interpretations of agroecology progressively expanded to encompass an understanding of agroecology as a practice and a movement.

2.2. Expansion of agroecology as a science: 1970s–1980s

Regarding the initial stage, few papers from the 1970s utilize the word "agroecology" (Figure 3). This quantity has changed dramatically since the 1980s. It has continued to rise with the rate of publishing. Numerous articles about agro-ecological zones, zoning, and agricultural output of various crops or livestock were published in the 1980s (Henricksen, 1986). By the end of the 1980s, agroecology and alternative agriculture began to include sustainability and sustainable development (Altieri, 1989). Agroecology has been a unique approach and conceptual framework for studying agroecosystems since the early 1980s. At the time, agroecology was the worldwide study of agroecosystems that preserve natural resources to create and oversee sustainable agroecosystems (Altieri, 1989). The 1970s saw the development of the agroecosystem's central idea. The ecologist Odum first proposed the term "domesticated ecosystems," referring to agroecosystems as a transitional state between artificial and natural ecosystems (Altieri, 1995). Research on traditional agricultural practices and agroecosystems in tropical and subtropical developing nations was another novel approach to agroecology at the time (Conway, 1987). During the 1970s and 1980s, Cox and Atkins (1979) was another significant agro-ecology publication. They addressed political, economic, and energy-related issues about agricultural systems in both developed and developing nations, offering a comprehensive overview and in-depth analysis of many components and dynamics in agroecosystems (Cox & Atkins, 1979).

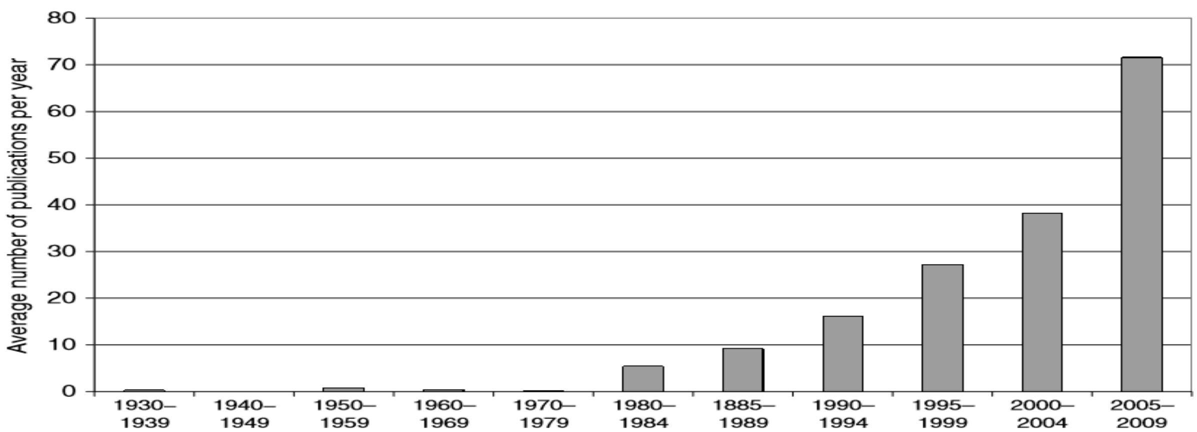

Figure 3. Average number of publications using the word agroecology or agroecological in the title or in the author keywords from different periods from 1930 to 2009 (Wezel & Jauneau, 2011).

2.3. Institutionalization and consolidation of agroecology: 1990s

Agro-ecological research developed and became more unified in the 1990s, and several significant textbooks were released (Altieri, 1995; Carroll et al., 1990; Gliessman, 1990). Around this time, publications about agro-ecological zones, zoning, land-use classification, characterization, sustainability, and sustainable agriculture skyrocketed (Thomas & Kevan, 1993). Thus, the 1990s saw the emergence of the topic of biodiversity in writings about agroecology. By the end of the nineties, agroecology publications began to use the phrase "soil" more frequently under issues like productivity, conservation, fertility, and zonation. Similar to the 1980s, publications still included the phrase "agroecosystem" in their titles or keywords; however, its prevalence was lower than that of the terms "biodiversity" or "sustainability" (Altieri, 1987; Johns, 1998).

2.4. New dimensions in agroecology: 2000–present

With the start of the twenty-first century, agroecology took on new meanings. According to some writers, agroecology has evolved beyond agroecosystems into food systems. Agroecology was first defined as "the integrative study of the ecology of entire food systems, encompassing ecological, economic, and social dimensions," or more simply, "the ecology of food systems" (Francis et al., 2003). Similar definitions of agroecology were offered by Gliessman (2007), who defined it as the science of applying ecological concepts and principles to the design and management of sustainable food systems, with a focus on real-world applications. Clements & Shrestha (2004) outline ten new dimensions of agroecology in comparison to traditional agronomic approaches: the natural dimension, technology and ecology, human ecology, non-crop biota, crop autecology, encompassing the agricultural landscape, closing the materials cycle, and a new philosophy of agriculture. 9 Publications on sustainability and sustainable agriculture have grown dramatically since 2000; nevertheless, they now primarily address sustainable development, biodiversity, and the addition of new subjects, including organic farming, agriculture, and agrobiodiversity (Wezel & Soldat, 2009).

2.5. Scales and dimensions in agroecology

Agroecology has evolved from the plot or field scale (1930s–1960s) to the farm or agroecosystem scale (1970s–2000s) (Figure 4 & 5), though more minor scale techniques are still in use today. This is clear by examining the various definitions and descriptions in publications. The definitions of agroecology provided by Gliessman (2007) and Francis et al. (2003) transcend this context by moving beyond the physical scale of space and into the realm of the food system. This dimension encompasses not only the local, regional, national, and international geographical dimensions but also the food production systems, society, and the economics and politics that are inextricably linked to one another, even though they cannot be explicitly assigned to a particular scale.

The evolution of agronomy and ecology, the two fundamental fields from which agroecology is developed, can be primarily linked to the shift in definitions and scale. However, other fields, like botany and plant physiology, zoology, and their applications to environmental and agricultural problems, are equally crucial. More disciplines have become involved over time and at larger sizes; these include sociology, geography, socioeconomics, and anthropology (e.g., dealing with cultures, customs, or indigenous knowledge). The primary subjects and goals of agro-ecological research vary depending on the scales and context in which they are used. Specifically, the food systems approach has brought fresh information to agroecology, opening up new disciplinary opportunities. Some of these are new, but others—like sociology—previously used to the agroecosystem method (in some circumstances) emerged more prominently in the 2000s. More of a food systems approach is needed because research on the new areas of rural poverty, rural development, and biodiversity protection has increased significantly faster than studies on agroecosystems.

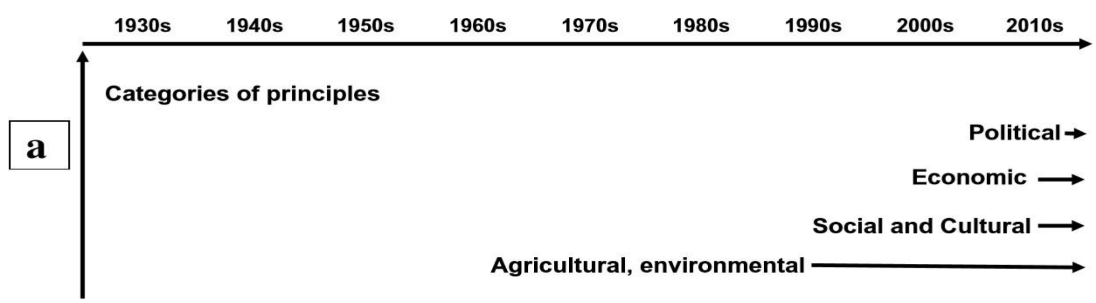

Figure 4. Historical evolution of disciplinary basis of principles articulated within agro ecology (Rahman et al., 2021)

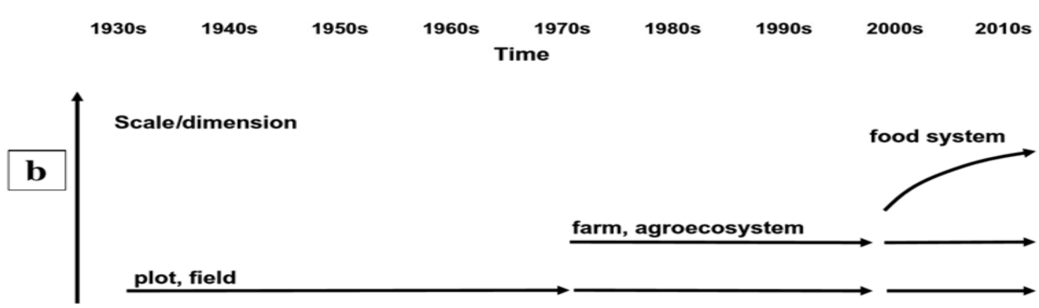

Figure 5. Historical evolution of scales in agro ecology (Rahman et al., 2021)

The agroecosystem approach is the second, more focused approach in agroecology. The agroecosystem scale is dominated primarily by continuing research, which also examines interactions with and effects on the environment (Martin & Sauerborn, 2006). Interactions between the economy, politics, and society are typically ignored. While agricultural production aspects are not explicitly mentioned, the Department of Crop Science (Agroecology Section) at the University of Göttingen provides a definition that does an excellent job of summarizing this: "Agro-ecological analyses focus on plant and animal communities, food web interactions, and conservation biology in temperate as well as tropical agricultural landscapes and agroecosystems." The definitions and concepts used in agroecosystem approaches may change based on how an agroecosystem is defined. An agroecosystem is sometimes considered the bigger end of the scale, a local or regional landscape where agriculture is conducted; for others, a farm is the equivalent of an agroecosystem (Conway, 1987).

Plot, or field scale, is where the third agro-ecological strategy operates. Crop-pest and crop-weed interactions are analyzed here almost entirely, focusing on natural processes. In certain instances, the analysis of pesticides' effects extends to crops, natural flora, and animals. Under this more constrained framework, research on animal husbandry frequently concentrates on the individual animal or the resources from one or more pastures, with little regard for the relationships and consequences for the environment or the agroecosystem (Wezel & Juneau, 2011).

3. Principles of agroecology

There are numerous diverse definitions and interpretations of agroecology. In 2019, a total of 197 countries endorsed the 10 components of agroecology as a framework to shape the Food and Agriculture Organization's (FAO) perspective on agroecology (Belmain et al., 2022). The elements were derived from a collaborative process including multiple stakeholders, which was organized by FAO. The 13 principles of agroecology were published by the High-Level Panel of Experts on Food Security and Nutrition (HLPE) in the same year. The HLPE serves as a platform for scientific and policy discussions within the UN Committee on World Food Security (CFS). Its main objectives are to promote informed policy debates and to offer impartial, thorough, and fact-based analysis. In 2017, the Committee on World Food Security (CFS) made a formal request to the High Level Panel of Experts (HLPE) to create a study focusing on agroecological methods and other advancements that promote sustainable agriculture and food systems, while also improving food security and nutrition. The HLPE compiled a roster of 13 principles constructing (Delvaux, 2018). CSOs, NGOs, and scholars worldwide now extensively employ these ideas. In addition, the HLPE associated each principle with one of the three operational principles of sustainable food systems, as outlined in a 2016 paper by Namirembe et al. (2022).

Figure 6. Illustrates the thirteen principles of agroecology and their connection to the operational principle of sustainable food systems. The central circles in the diagram depict the primary factors that contribute to a successful transition, as outlined in the 13 Principles of Agroecology (2019).

The HLPE established three principles that direct the development of a sustainable food system. Although there may be instances where trade-offs between the principles are unavoidable, there exist significant synergies between them that facilitate the identification of mutually beneficial solutions. Enhancing the ability to withstand climatic change, animal diseases, and price fluctuations can promote investments and enhance productive efficiency (IPES-Food, 2021). The interconnectedness of the three operational principles emphasizes the necessity for a comprehensive approach to the food system.

3.1. Improve resource efficiency

Enhance Resource efficiency entails maximizing the utilization of resources to improve economic profitability, minimize adverse environmental effects, and improve the social circumstances of small-scale farmers, pastoralists, and family farmers who have limited resources or are marginalized. By reducing the disparity in agricultural productivity between the top and worst performers in a region by the use of both established methods and innovative technologies, agricultural output can be boosted, leading to advantages for livestock and animal feed production. This approach has the potential to enhance the diets, nutrition, and economic welfare of vulnerable communities (Cacho et al., 2018).

1. Recycling: Give priority to utilizing local renewable resources and strive to efficiently close the loops of nutrients and biomass.

2. Input reduction: Minimize or eradicate reliance on purchased inputs and enhance self-reliance.

3.2. Enhance resilience

Enhancing Resilience involves strengthening the capacity to endure and recover from shocks caused by the environment, economy, finance, and animal diseases, while also increasing the efficient use of resources. This entails developing strategies to improve the ability to adapt, manage risks, and respond to changing circumstances. Through the development of resilience, both communities and agricultural systems are able to enhance their ability to withstand and overcome obstacles and uncertainties. This enables them to effectively and sustainably utilize resources, even in the midst of adversity (Sinclair et al., 2019).

1. Improve soil health by effectively controlling organic matter and boosting soil biological activity to promote optimal plant growth.

2. Promote the well-being and welfare of animals by ensuring their health.

3. Preserve and improve the variety of species, functional diversity, and genetic resources to ensure the overall biodiversity of agroecosystems at different scales, including field, farm, and landscape levels.

4. Foster beneficial ecological interactions, synergy, integration, and complementarity among the components of agroecosystems, including animals, crops, trees, soil, and water, in order to enhance their overall effectiveness.

5. Promote economic diversification by enhancing the financial autonomy and value-added prospects of small-scale farmers, allowing them to effectively meet consumer demands.

3.3. Ensuring social equity and responsibility in a secure manner

Secure Social Equity/Responsibility encompasses the guarantee of impartiality and responsibility in dealing with a wide range of social and ethical issues within society. It includes the distribution of income, the protection of human rights, the promotion of gender equality, the provision of social protection, and the preservation of cultural heritage. The concept entails the obligation of individuals, corporations, and collectives to safeguard the environment, advance human welfare, and improve animal welfare. Attaining a state of secure social fairness and responsibility necessitates employing a range of different and context-specific strategies, as societal norms and practices differ throughout countries and communities (Snapp, 2017; IPES-Food, 2021).

1. Co-creation of knowledge: Facilitate the collaborative generation and horizontal dissemination of knowledge, encompassing both local and scientific innovation, particularly through the interchange of information amongst farmers.

2. Social values and diets: Establish food systems that are rooted in the culture, identity, tradition, and social and gender equality of local communities, in order to offer nutritious, varied, seasonal, and culturally suitable diets.

3. Equity: Ensure equitable and sustainable livelihoods for all participants involved in food systems, particularly small-scale food producers, through the principles of fair trade, fair employment, and protection of intellectual property rights.

4. Enhance connectivity: Facilitate equitable and efficient distribution networks and reintegrate food systems into local economies to establish close proximity and trust between producers and consumers.

5. Land and natural resource governance: Enhance institutional arrangements for land and natural resource governance, including by acknowledging and assisting family farmers, smallholders, and peasant food producers as effective stewards of natural and genetic resources.

6. Participation: Encourage the active involvement of food producers and consumers in decision-making processes to promote decentralized governance and local adaptive management of agricultural and food systems.

4. Methods and approaches in agroecology

Agro-ecological farming methods emphasize large-scale food production while optimizing ecological processes and ecosystem services. They do this by incorporating them as core components into the practice's development rather than merely depending on conventional methods like applying synthetic pesticides and fertilizers or technological advancements like genetically modified organisms. Agroecological practices help to improve agroecosystems in a way that lasts because they are based on many different ecological processes and ecosystem services. These include biological nitrogen fixation, natural pest control, soil and water conservation, biodiversity preservation, and carbon sequestration (Altieri et al., 2017; Gambart et al., 2020). While some of these methods were created more recently, others have been used to varied degrees in various parts of the world for years or decades.

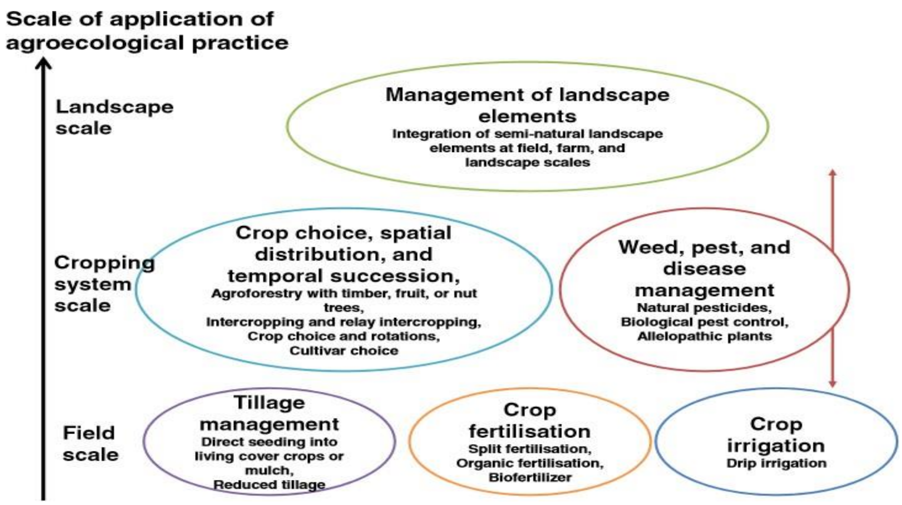

Figure 7. Displays many classifications of agroecological activities. Their applicability spans from the scale of individual fields to the larger scale of entire landscapes. Practices are typically implemented either at the field level or on the scale of the cropping system. The inclusion of weed, pest, and disease control measures in the arrow suggests that these activities are implemented at both the field scale and landscape level (Wezel et al., 2014).

Three (often) successful stages define the agricultural transition towards sustainable agriculture: efficiency increase, substitution, and redesign (Gelats, 2003; Sachet et al., 2021). However, some farmers go straight into the third stage when they change their agricultural practices significantly, such as switching to agroforestry or no-tillage systems. The term "efficiency increase" describes methods that boost crop yield while consuming fewer inputs (such as water, fertilizer, and herbicides). Substitution practices include changing input or technique (natural pesticides instead of artificial pesticides). Lastly, redesign describes a complete overhaul of the farming or cropping system (Trabelsi et al., 2016).

Additionally, it is possible to differentiate between strategies that pertain to crop management and those that control landscape components. There are various categories of crop management practices: (1) practices that deal with crop selection, crop spatial distribution, and crop temporal successions; (2) tillage practices; (3) fertilization practices; (4) irrigation practices; and (5) weed, pest, and disease management practices. When managing landscape elements, there are differences between field- and farm-level and landscape-level techniques (Wezel et al., 2014). Figure 7 summarizes the several practice categories and displays the application scales for each.

Agroecology, a novel agricultural system, has acquired the confidence of small and marginal farmers in various nations throughout the past 20 years. Many agricultural techniques, such as permaculture, agroforestry, organic farming, biodynamic farming, ecological farming, green manure, organic manure, intercropping, biological pest management, and more, are included in agroecology, also known as agricultural ecology. Some of the significant agro-ecological practices gaining popularity are described below.

4.1. Permaculture

Permaculture, a holistic agricultural methodology developed by Bill Mollison and David Holmgren, enables small-scale farmers to provide a satisfactory income while preserving and conserving their land. By employing this methodology, they are able to meticulously regulate the soil and water, leading to an ecosystem that supports life and protects the environment. The fundamental principle of this method is to collaborate with nature instead than opposing it. Permaculture has gained considerable traction among both affluent and emerging nations, attracting a substantial following of individuals and institutions. Permaculture can be defined as a self-sustaining system that involves the cultivation of perennial plants and animals that are beneficial to humans, and this system is designed to be interconnected and continuously evolving. Permaculture seeks to mimic the natural processes of the environment in order to meet fundamental human needs in a manner that promotes restoration, regeneration, and long-term sustainability. The concept is grounded on the notion that our world possesses limited resources and advocates for the imposition of restrictions on human consumption and industrial expansion (George & Jafri, 2014).

Permaculture principles: The core of permaculture is rooted in its focus on upholding ethical standards. The three ethical principles of permaculture encompass:

1. Foster environmental stewardship
2. Promote social well-being
3. Redistribution of excess resources to the planet and its inhabitants, often known as "fair share."

4.2. Agroforestry

Agroforestry is a method that uses land management to boost agricultural output. With this approach, trees are integrated into the farming system, allowing for the coexistence of trees, crops, and cattle on the same plot of land. In agroforestry, annual agriculture activities (pasture and crops) and trees' delayed, long-term productivity (timber and services) are combined on the same land. Planting trees on the agricultural plot or planting crops in forested regions accomplishes this. When looking at productivity, it has been discovered that 100 hectares of agroforestry yield the same amount of agricultural products as 140 hectares of farmland with separate plantings for crops and trees. On agroforestry plots, this impact is the consequence of encouraging complementarity between crops and trees. In new forestry plantations, weeds that naturally occur are thus replaced by harvested crops or pasture since they require less upkeep and make better use of the environment. Agroforestry yields profits that are on par with or higher than those of monocultures (Padel et al., 2018).

4.3. Conservation agriculture

Conservation agriculture is a globally recognized concept, commonly employed in regions with high susceptibility to soil erosion. It is extensively observed throughout North and South America, as well as Europe. The system is based on three fundamental principles:

1. Crop rotation
2. Minimal soil disruption
3. Optimal soil coverage

Many crops are established with zero-till in conservation agriculture. There is no additional soil disturbance besides straight sowing into the previous crop's stubble. Retaining the soil in the field in a consolidated form helps avoid erosion, and such a system has high speed, low cost, and low energy use. When crop waste is chopped and left on the surface, maximum soil cover can be attained by planting immediately after harvest. Cover crops are planted in areas where the rotation requires a longer intercrop time. More study is needed on the complete range of advantages associated with autumn-sown cover crops, sometimes referred to as catch crops. Further investigation is necessary to ascertain the economic benefits relative to the initial cost of their development. Mustard, rye, phacelia, fodder, and oil radish are common cover crops that are being used and researched. According to new research, using them in sustainable integrated farm management rotations can have many benefits, such as stopping soil erosion, lowering nitrogen leaching by 65–70%, making more nitrogen available for the next main crop, increasing soil organic matter, fixing some soil compaction issues, lowering weed loads, and raising yields (Third World Network Staff, 2015; Padel et al., 2018).

4.4. Organic farming

Organic farming refers to an agricultural method that aims to establish integrated, humane, environmentally friendly, and commercially viable agricultural systems. This encompasses the attainment of elevated levels of environmental preservation, sustainable resource utilization, animal well-being, food security, safety and quality, social equity, and financial feasibility. To ensure satisfactory levels of crop, livestock, and human nutrition, protection from pests and diseases, and a fair return on investment, it is essential to manage self-regulating ecological and biological processes and interactions. This involves relying as much as possible on renewable resources derived from local or farm sources, and operating within closed cycles. To promote an autonomous and self-sufficient system, efforts are made to reduce the need of organic or chemical external inputs (George & Jafri, 2014; Third World Network Staff, 2015).

Although organic farming regulations prioritize limiting inputs such as synthetic fertilizers, pesticides, and genetically modified organisms (partly because they are easier to audit), organic farming techniques include the following, as stated by Padel et al. (2018):

• Sustaining soil fertility through the cultivation of legumes and green manures;

• Preserving nutrients by striving to complete nutrient cycles, minimizing waste and wasteful exports, and recycling nutrients whenever feasible;

• Opting for moderately insoluble mineral nutrition sources, such as rock phosphate, instead of highly soluble or processed forms;

• Decreasing energy consumption and increasing dependence on renewable energy sources;

• Employing shallow plowing and reduced tillage methods to safeguard the soil and its biological processes;

• Implementing strategies to preserve nutrients and prevent contamination when managing manures and slurries, such as composting;

• Using crop rotations and polycultures to restore soil fertility, help control weed, pest, and disease problems, provide sufficient livestock feed, and maintain a profitable system;

• Replacing biocides for weed, pest, and disease control with preventive cultural measures, supplemented by mechanical, thermal, and biological controls if required;

• Integrating livestock with cropping systems (except in the case of stockless horticultural and arable farms), with both ruminants and non- ruminants ranging freely (i.e., no intensive, permanently-housed pig, poultry, and feedlot cattle production);

• Relying as far as possible on home-grown feeds for livestock, limiting stocking rates to levels consistent with the EU nitrates directive, and thus reducing pollution risks;

• Mixing livestock species, such as sheep and cattle or sheep and poultry, to help control parasites and diseases and improve grassland management;

• Maintaining animal health through preventive management (including breeding, rearing, feeding, and housing) and health plans in preference to prophylactic medication (e.g., with antibiotics or anthelmintics);

• Objective of organic agriculture is to advocate for the well-being of animals, ensuring that they have the opportunity to express their natural behaviors through appropriate housing design, controlled stocking rates, limitations on mutilations, and the use of conventional treatments when necessary to prevent suffering caused by sickness or injury.

5. Challenges and limitations of agroecology

In a variety of contexts, locally appropriate agro-ecological practices have the potential to improve adaptation to climate change and boost livelihood resilience at the field and farm levels. They also frequently have sizable co-benefits related to mitigation that could aid in funding their establishment. However, before their full potential can be achieved, obstacles to their adoption must be removed at all levels of the hierarchy (Figure 8). In addition to implementing comprehensive performance measurements for agricultural systems that consider social and environmental externalities, they also need to address market failures and alter policies that produce perverse incentives (Prost et al., 2023). The development and promotion of agro-ecological practices involve a diverse range of stakeholders, and co-learning among them requires a reconfiguration of the relationship between formal science and local knowledge, including bridging perspectives and emphasizing gaps between social movements and the scientific establishment. Policy procedures across sectors and scales must be integrated to create an environment conducive to adopting agro-ecological practices (Francis & Wezel, 2015).

Though these are comprehensive demands requiring coordinated thought and action, the recent shift in public opinion toward acknowledging a climate emergency may generate the necessary pressure to persuade public and private sector decision-makers, scientists, consumers, and farmers to take the necessary steps to bring agro-ecological practices up to par with alternatives, which is a prerequisite for their wider adoption.

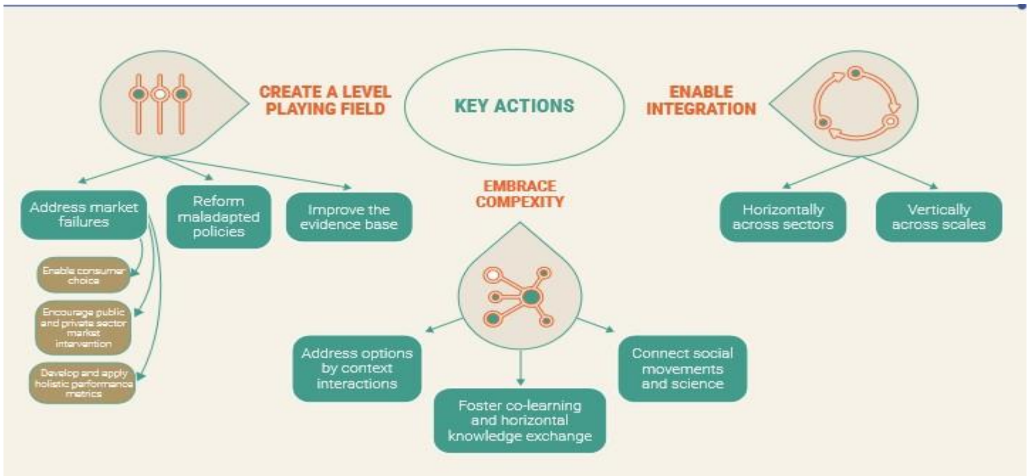

Figure 8. Key actions required to enable adoption of agroecological practices at scale to build resilience of farming and food systems (Francis & Wezel, 2015).

The European Commission's knowledge center lists the following obstacles that must be solved in order to advance agroecology:

• An enabling environment is necessary for agroecological transitions to provide farmers with positive incentives and support them in the process of transforming their systems to make them sustainable and profitable.

• Policies should be implemented to prioritize research that supports agroecology and other sustainable agricultural approaches.

• Rural education and extension systems should shift their focus from single disciplines and increasing yields of single commodities to a collaborative approach that combines scientific knowledge with farmers' knowledge.

• The diversity of markets that prioritize local and regional production and consumption should be strengthened to promote diversified agroecological production within short supply circuits.

• Agroecological transitions require greater integration across sectors, disciplines, and actors in order to achieve multiple objectives at different scales. Specifically, they require governance solutions that effectively coordinate actions across many landscapes and territories.

6. Case studies and success stories

6.1. Subak system in Bali, Indonesia (Rahman et al., 2021)

The subak system in Bali, Indonesia, has been included on UNESCO's List of World Heritage Sites as a cultural landscape since 2012. As to the World Heritage Committee, subak is a collaborative water management system that incorporates democratic and egalitarian farming techniques. It also represents the Tri Hita Karana Philosophy, which unifies the spiritual, human, and natural domains.

The subak system exemplifies the need to view food production and consumption in a comprehensive manner. The term typically refers to the conventional method of watering the rice fields in Bali. Farmers convene in a subak association to oversee the distribution of irrigation water and mitigate conflicts arising from the utilization of shared water resources. The subak system, however, encompasses more than just an irrigation system. The traditional rice plantation system serves as a method of pest control, regulates the timing of rice planting, and supports the ongoing observance of Balinese religious rituals. The entire rice production cycle, encompassing the preparation of the rice fields to the harvesting season, is not to be regarded as an isolated procedure, but rather as intricately connected to a series of subak ceremonies. Each constituent of the subak system, such as the organization, rice field terraces, farmers, and ceremonies, must be seamlessly interwoven to form a functional subak.

Safeguarding the subak system entails preserving not just rice production, but also cultural customs, ancestral agricultural wisdom, and the social bonds among farmers. Knowledge pertaining to subak is transmitted through agricultural practices as well as social, cultural, and religious activities within Balinese community. As a result, subak serves as both a culinary delicacy and a significant cultural establishment. Rice and other food items in Balinese culture hold both economic and symbolic worth, representing the ideological and cultural relevance of the Balinese people. While subak is primarily focused on rice production, it may also be viewed as an integrated food system that encompasses the production and consumption of rice, as well as the dissemination and modification of food-related information.

Through the perspective of human and social values, subak can be perceived as a result of collaborative efforts involving multiple stakeholders. The subak organization primarily oversees the management of the system, with farmers taking charge of its operations and participating in communal decision-making. Nevertheless, priests, merchants, artisans, and other people frequently participate in various phases of the rice production process. Hence, the prosperity of rice cultivation and the maintenance of this customary system rely on safeguarding the societal significance and coherence of subak associations. Therefore, it is imperative to enhance the social relationship and the subak organization in order to guarantee the long-term viability of the subak system and safeguard farming as the primary source of subsistence for the community. Despite the predominance of men in farming, the religious component of the subak system allows for the involvement of women in agricultural pursuits. Women have also participated in subak as temporary laborers during the harvest period, allowing them to earn supplementary cash for their families.

The subak system exemplifies the significance of collaborative knowledge development and sharing in the shift towards a sustainable food system. Facilitating farmers' access to trial and error with novel rice cultivation techniques is essential for fostering knowledge discovery and stimulating the enthusiasm of young farmers towards the agricultural process. This approach also facilitates farmers in identifying an appropriate adaptive strategy to mitigate the effects of climate change. The subak system has undergone extensive refinement over a millennium of experimentation, and its sustainability relies on farmers' capacity to adjust to prevailing social, economic, and environmental obstacles. The absence of co-creation had a significant impact during the Green Revolution in the 1970s, as it resulted in the marginalization of farmers' knowledge due to the implementation of a globally standardized farming strategy. As a result, there was a decline in crop yield, extensive damage to rice fields, and the contamination of numerous farmers, which stands in stark contrast to the rise in productivity.

Culture and culinary customs are integral elements of subak. The subak system adapts to the cultural and environmental circumstances of Balinese civilization. An example of contrasting water management can be observed between Subak Jatiluwih, characterized by terraced landscapes, and Subak Pakerisan, characterized by a relatively flat terrain. The farming cycles are intentionally synchronized with the Balinese calendar and other religious festivals. The purpose of this approach is to maintain a balance between economic and cultural activities in Bali, while also guaranteeing the sustainability and efficiency of rice production in the face of increasing environmental constraints on the island. The transmission, collaborative development, and dissemination of knowledge pertaining to the subak system, like other forms of indigenous knowledge, occur through narratives, exemplary methods, informal gatherings, as well as various religious and cultural occasions. The knowledge of Subak may be integrated into several other Balinese systems, including temples, palaces, and customary villages, as it plays a vital role in the culture. In Bali, several culinary traditions serve as a means of establishing a connection between individuals and their forebears, shown by the Balinese practice of offering a little part of food to their ancestors before to consuming it themselves. Different ceremonies in Bali require a variety of rice varieties and delicacies, highlighting the importance of local food production in preserving Balinese culture and religion.

6.2. The BigPicnic project (Rahman et al., 2021)

The second case study examines the BigPicnic project, which is supported by the European Union. The large-scale picnic event took place from May 2016 to April 2019 and involved a partnership between 19 entities, including fifteen botanical gardens from 12 European nations and one from Uganda. According to the FAO, addressing local concerns is more efficient when agroecological solutions are developed collaboratively through participatory procedures and use information that is specific to the local context. Moreover, the BigPicnic partners collaborated with their local communities to arrange various activities centered around many food security concerns, with a significant emphasis on co-creating and sharing knowledge.

BigPicnic was a collaborative project that focused on the joint creation and dissemination of information regarding food security, the food system, and the future of food. This was achieved through a series of events, exhibitions, and science cafés that were developed in partnership with various stakeholders. The activities were centered around co-creation, with the goal of fostering shared values through engagement with the communities. Consequently, varying degrees of proficiency were regarded as equally significant in this procedure, as the participants endeavored to establish a connection founded on discourse and the interchange of thoughts and principles. The co-creation process provided a valuable platform for integrating scientific knowledge with traditional and indigenous perspectives from local tribes in Uganda and African diaspora communities in Belgium. Additionally, it incorporated practical insights from various stakeholders in the food industry, including farmers, producers, and traders. The botanic gardens and co-creators collaborated to develop a total of 102 co-created science cafés and 103 exhibitions. These events covered many subjects such as climate change, food waste, biodiversity, urban gardening, meat consumption, and eating cultures. For instance, individuals in the botanical park of Leiden collaborated to develop an open-air display that explored many facets of food origin, manufacturing, and consumption. Using their perspectives, schoolchildren in Norway collaboratively curated a picture exhibition centered around the themes of food and climate change. The botanical gardens in Warsaw and Edinburgh utilized digital storytelling techniques to highlight the tales, stories, and memories of different members of the public. In general, the co-creation processes emphasized the significance of food as a representation of cultural history and the importance of food heritage in guaranteeing food security and sustainability. Moreover, this process allowed co-creators to explore and exchange diverse food heritage practices and traditional forms of knowledge.

BigPicnic fostered an inclusive environment that enabled European individuals with diverse origins, abilities, and experiences to actively engage in the collaborative process and ensure their perspectives and opinions were acknowledged. The disclosure of personal and societal values of individuals involved in the food system, such as food producers, distributors, and consumers, occurred as a consequence. These emphasized the significance of human and social values in fostering well- being and enhancing livelihoods within communities. Within this particular framework, the inclusion of food education emerged as a prominent determinant, as individuals emphasized the significance of possessing knowledge regarding food resources, acquiring culinary proficiencies, preparing nutritious meals, and embracing a well-rounded dietary regimen. Another crucial consequence associated especially with excellent health and wellbeing was the significance assigned to individuals' dietary selections. The focus was on selecting organic or natural products, affordability of food items, and the significance of regional or local cuisine. Simultaneously, the availability of food was regarded as the fundamental factor capable of addressing hunger.

The recognition of food as a manifestation of cultural legacy became apparent through various collaborative events, mobile exhibitions, and science cafés. This feature illustrated the interrelationships among food culture, traditions, and food security. The eating behavior of individuals was greatly influenced by traditional dietary practices. Particular categories of food, plants, and cuisines have historically been ingested due to their familiarity or the cultural affinity individuals have towards them. Specific categories of food often became linked to specific circumstances (such as events, celebrations, rituals) that were connected to national, ethnic, regional, or local identity. This aspect was specifically emphasized by African diaspora populations in Belgium and local communities in rural Uganda. In Belgium, a number of events were organized in collaboration with diaspora members, with a specific focus on edible insects and their role in ensuring food security. These events provided valuable insights into dietary habits and practices, particularly the tradition of entomophagy and the importance of culturally appropriate cuisine. The activities in Greece involved the collaborative creation of experiences centered around superfoods, fragrant plants, and traditional herbs that provide nutritional or therapeutic qualities. Simultaneously, Bulgarian participants expressed their affinity for locally cultivated vegetables that are utilized in customary culinary preparations. The Mediterranean diet has gained significant importance among audiences in Spain, Portugal, Italy, and Greece because to its association with health, seasonality, cultural affinity, and its connection to a certain region and locale.

The significance of cuisine in shaping cultural identity and the availability of ingredients from one's native country were also prominent in the events that addressed the ambitions and principles of expatriate populations. Members of the African community in Belgium emphasized the significance of having access to food crops from their home countries, highlighting the crucial factors of quality and price. Simultaneously, those with a nomadic heritage emphasized the significance of food in reestablishing a connection with their native area through recollections, customs, and routines.

The participants who were connected to diasporic communities not only emphasized the prevalence of food, but also its significance in evoking unique memories and narratives that individuals and groups hold dear. Childhood memories associated with culinary traditions and the utilization of specific plants and meals played a significant role in shaping attitudes towards and understanding of food.

6.3. Farm networks in Switzerland (Jeanneret et al., 2021)

Agro-ecological practices for crop rotation have been used at commercial farms in Switzerland to cut down on chemical pesticide use. Scientists presented farmers with 20 agro-ecological action levers based on agro-ecological concepts. These included mixed cropping, wildflower strip implementation, mechanical weed control, and under-sowing. In 2019, farmers who were involved in the project made decisions for the specific methods to be implemented in a single field over a period of six years as part of a crop rotation system. Agricultural practitioners are highly motivated to minimize the utilization of chemical pesticides in order to promote the well-being of both humans and the environment. Nevertheless, based on initial assessments conducted after co-innovation workshops with 70 farms, it appears that they are reluctant to engage in complete whole-farm arrangements. The primary obstacles include a) the potential for decreased production and quality, b) limited market demand for specialized crops, c) inadequate understanding of certain techniques, and d) inherent resistance to adopting new approaches. After one year of implementation, consistent communication among scientists, advisors, and farmers has effectively reduced resistance to changes. Furthermore, the acquisition of knowledge regarding certain methodologies has advanced through the aforementioned process. However, it is important to note that not all innovative methodologies have been put into practice. Farmer-to-farmer interactions have been vital to all of that. It is the primary unlocking lever. Data analysis is ongoing concerning the possible yield drop. None of the participating farms have planted any specialized crops. This specific initiative will not address the issue of introducing specialized crops, which affects the entire value chain of agricultural production. Results from intermediaries will be shared during the study, but by the time the crop rotation ends in 2025, the consequences of agricultural practices will be best examined.

6.4. Punarvasu family farm in South Karnataka, India (George & Jafri, 2014)

Punarvasu, a conventional family farm spanning five acres, is situated around 15 kilometers to the south of Udipi and 3 kilometers inland from the southern coast of Karnataka. In 2007, the family initiated the process of converting the farm to permaculture. During the initial year, they constructed an extensive water harvesting system along with two catchment ponds, one located at a higher elevation and the other in the middle of the farm. Additionally, they created gulley plugs to regulate the water flow across the entire property. In addition, a grey-water reuse system was implemented, specifically designed for the purpose of recycling water used in dish and clothes washing. In the second year, they implemented grey-water reuse systems, one for an inside sink and another for the bathhouse that supplies water to a small nursery. Subsequently, they excavated pits for a petite cashew orchard that accommodates multiple species, which was planted during the monsoon season. Additionally, they introduced cocoa trees into the preexisting coconut and pepper orchard. In addition, they conducted experiments including the construction of a solar dryer and a miniature playhouse. The banana clumps in the banana orchard were connected by bunding, which involved establishing center mulch pits. These pits were then planted with pineapple, sweet potato, and papaya. Subsequently, they additionally implemented a biogas facility specifically designed for culinary use. In addition, they undertook the task of designing and converting the cow barn into accommodations for guests, expanding the primary reservoir, establishing a lush garden like a jungle, and persisting in constructing and planting circular arrangements of banana plants. Annually, they organize practical workweeks and training sessions. They persist in residing on the ancestral agricultural estate and partake of sustenance cultivated on the land.

6.5. Cuba food crisis (Nicholls & Altieri, 2018)

Agroecology was essential in mitigating Cuba's food crisis triggered by the disintegration of the communist bloc in 1989–90 and the following intensification of the US trade embargo. Cuban farmers have the potential to increase food production without relying on scarce and expensive imported agricultural chemicals by adopting more diverse and agro-ecologically integrated farming systems. The National Association of Small Farmers (ANAP), which had achieved a presence in one-third of all peasant families in Cuba by 2010, advocated for the implementation of the Campesino a Campesino (CAC) technique, enabling a rapid change in peasant agriculture. The movement has expanded to encompass over 200,000 peasant families, which represents around 50% of the Cuban population. These families have successfully diversified and improved their output without relying on foreign resources. As a result, the contribution of Cuban peasants to the overall production of food in the country has experienced a substantial growth. Agro-ecological practices are utilized in approximately 46-72% of peasant farms, which account for more than 70% of domestic food production. These practices are particularly prevalent in the production of roots and tubers (67%), small livestock (94%), rice (73%), fruits (80%), as well as honey, beans, cocoa, maize, tobacco, milk, and meat.

Recent observations over the past decade have demonstrated that a significant number of these small-scale agricultural farms display remarkable resilience in the face of climate-related disasters. Researchers conducted an agricultural assessment in the provinces of Holguin and Las Tunas forty days after Hurricane Ike struck Cuba in 2008. It was discovered that farms with a variety of crops experienced a 50% decrease in yield, while adjoining farms that grew only one type of crop experienced losses of 90-100%. Similarly, farms maintained with agroecological practices had a more rapid restoration of productivity (80-90% within 40 days after the hurricane) compared to monoculture farms. These assessments highlight the need of augmenting plant diversity and intricacy in agricultural systems to decrease susceptibility to severe climatic occurrences, a tactic well ingrained among Cuban farmers.

Cuba has made impressive strides in urban agriculture, boasting a total of 383,000 urban farms that occupy 50,000 hectares of previously unused land. These farms have successfully yielded over 1.5 million tons of vegetables, with the most productive urban farms achieving a remarkable yield of 20 kilograms per square meter per year of edible plant material. It is worth noting that these farms achieve such high yields without the use of synthetic chemicals, which is equivalent to a yield of 100 tons per hectare. Urban farms provide over 70% of the fresh vegetables consumed in places like Havana and Villa Clara. The proliferation of urban agriculture on the island was a direct response to the logistical challenges associated with delivering food from rural regions. The establishment of urban farming heavily relied on social structure and collaborative activity. Nevertheless, the crucial role of government support became evident through the provision of extension services, key inputs, and improved land accessibility.

6.6. Lessons learned and best practices from these case studies

The case studies illustrated the importance of considering the social, cultural, and geographic environment when applying agro-ecological practices. The Subak system case study demonstrated how agricultural systems that fail to incorporate food history might lead to the demise of the food system and its participants. Although it is commonly believed that traditional food systems could be more flexible and able to handle current or upcoming difficulties, Subak has proven that it can adjust to the shifting demands of its community. However, the advent of modern farming techniques and Eurocentric farming knowledge destroyed the Subak society's ancient knowledge and gradually undermined the agricultural system's worth and practice. Thus, the need for more of the full range of learning opportunities and experiences represented in the subak co-creation and sharing system has a direct impact on the sustainability of the food system. Thus, this study suggests that food heritage could be understood as the "glue" that makes the food system and knowledge operate, as opposed to considering food heritage as a component of an agroecology or food system.

The BigPicnic case study illustrated how crucial information sharing and co-creation are to the involvement of food actors and stakeholders at different phases of the food system. This is especially important to establish an efficient and sustainable agriculture and food system and promote food innovation, adaptation, and knowledge transfer. Co-creation and information sharing might take the form of interactive activities, exhibitions, casual talks, food stories, storytelling, and religious and cultural events. In order to dive deeper into the development and sharing of traditional and local food knowledge, as well as the specific social, physical, and cultural environment in which this knowledge originates, BigPicnic emphasized the need for co- creation and knowledge sharing. This relates to the long-standing goal of agroecology, which is to integrate traditional and local food knowledge into the basic understanding of the food system. It also outlines approaches to accomplishing this goal by using a heritage lens.

According to a case study of Swiss farm networks, farmer-to-farmer connection is essential to implementing agro-ecological practices on farms. Frequent contact between the adviser, farmers, and scientists is crucial for large-scale implementation. For effective implementation, research on potential yield loss, the value chain of agricultural production, and cutting-edge technology will be required. The Punarvasu family farm case study demonstrated how even a single family can apply agro-ecological principles to a farm. They use the idea of permaculture as the foundation for their sustainable farming ecosystem. We can infer from these case studies that establishing a sustainable food system is feasible at both the farm and landscape scales.

The Cuban case study demonstrates the value of agroecology in increasing agricultural output without resorting to costly and dangerous imported chemicals. During the US trade embargo, the food productivity of Cuban peasants increased. Climate disaster resilience is higher on agro-ecologically managed farms. This teaches us that the concepts of agroecology can be a workable answer to costly contemporary farming issues and climate change.

7. Future food systems

Future food systems will be more resilient, democratic, and sustainable to feed a growing population while reducing the adverse environmental effects of agriculture. The shift from extensive monoculture farming to diverse agro-ecological systems will be one of the most significant. Farmers will embrace the idea of combining polyculture—growing a variety of crops—to improve soil fertility, reduce pest and disease outbreaks, and increase biodiversity. This change will aid in restoring ecosystems, water conservation, and decreasing greenhouse gas emissions. The future food system will probably see some significant changes to address the issues of nutrition, food security, and sustainability. Key components of the food system of the future include:

(1) Increased emphasis on plant-based diets: As knowledge of the advantages of plant-based diets for health and the environment increases, future food systems are expected to shift toward a greater percentage of plant-based foods. This involves increasing the yield and consumption of whole grains, legumes, fruits, vegetables, and plant-based protein substitutes.

(2) Sustainable and regenerative agriculture: Adopting regenerative and sustainable agriculture practices will be highly prioritized. This involves reducing the amount of synthetic pesticides and fertilizers used on agricultural fields, encouraging crop diversification, improving soil health, and promoting biodiversity.

(3) Precision farming and technology: The future food system will depend heavily on technology, especially precision farming methods. Drones, sensors, data analytics, and robotics will all help to maximize farming productivity, reduce waste, and enhance resource efficiency.

(4) Vertical and urban farming: Due to growing urbanization and a shortage of arable land, vertical and urban farming systems will likely increase. By utilizing innovative methods like hydroponics, aquaponics, and vertical stacking, these systems enable food production in urban areas, reducing the need for long-distance transportation and land use.

(5) Reduced food waste and improved supply chains: Reducing post-harvest losses and strengthening supply chains will be the future food system's top priorities in order to solve the problem of food waste. Food will be delivered to customers on time and without waste, with implementation of improved distribution, transportation, and storage technologies.

(6) Sustainable fisheries and aquaculture: As the world's fish populations continue to diminish, more sustainable practices in aquaculture and fisheries will be needed. Better management techniques, less overfishing, responsible aquaculture methods, and preserving marine habitats might all be part of this.

(7) Food system resilience and climate adaptation: Climate change will bring extreme weather and altered growing seasons. Thus, resilience and flexibility will be critical for the future food system. This covers the creation of crops resistant to climate change, better water management techniques, and applying climate-smart agricultural methods.

(8) Enhanced food traceability and transparency: The future food system will require increased traceability and transparency due to consumer desire for information about their food's origins and production methods. Using block chain technology to deliver accurate data about the whole supply chain might be necessary.

(9) Localized and community-centered food systems: The food system of the future is expected to become more localized and community-focused, with residents having direct access to fresh, locally grown food and a deeper relationship with farmers.

Long-distance transportation-related carbon emissions can be decreased, local economies can be strengthened, and food security can be promoted.

The future food system will be defined by a stronger focus on resilience and sustainability and a move toward plant-based diets. Technology will mainly enhance supply networks, decrease waste, and optimize farming methods. Community-centric strategies, food traceability, and climate adaptation will also shape the future food system.

8. Conclusion

Food security is a global policy priority that various stakeholders, including governments, NGOs, the scientific community, development and environmental organizations, and agribusiness firms, extensively address. The current industrial farming model has yet to succeed in achieving food security. It has been abundantly evident that a paradigm shift in agriculture is necessary to eradicate poverty and hunger and that conventional economic practices must change. The discussions around agroecology and sustainable intensification highlight how urgent and complicated the problem of food security is. The discourse area is characterized by divergent opinions on how to alter the paradigm of the current agricultural system, leading to heated and often emotionally charged talks. It becomes apparent that a swift or effortless answer will not suffice. Nevertheless, it is imperative to not only increase food production, but also tackle the underlying factors that contribute to food insecurity and effectively meet the forthcoming problems. This indicates a particular emphasis on small-scale farmers, who play a crucial role in attaining food security, as well as the overall necessity to enhance resource efficiency in order to boost yields in regions where they are insufficient. Additionally, it is necessary to ascertain if production will require a growth of 100%, 70%, or 60% by the year 2050, and we must define the means by which this objective can be accomplished. Enhancing their availability of resources like land, water, seeds, and fair marketplaces, empowering nearby people, particularly women, and encouraging the exchange and propagation of agricultural knowledge locally are essential. In addition, cutting down on food waste and post-harvest losses and reevaluating resource-intensive consumption habits are crucial prerequisites for ending hunger and poverty worldwide. Narrow production-focused approaches are unlikely to address these issues and run the danger of marginalizing other factors.

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