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Conversion of farming systems into organic bio-intensive farming systems and the transition to sustainability in agro-ecology: Pathways towards sustainable agriculture and food systems

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Abstract. The present farming systems of the world are under pressure to meet multiple demands, and it is clear that addressing these challenges requires a collective effort. This includes supporting the livelihoods of smallholder farmers, conserving biodiversity, offsetting emissions, and adapting to climate change to feed the ever-growing population. In the coming decades, agricultural systems must address significant challenges to produce sustainable bio-energy, adapt and mitigate global climate change, improve water quality and availability, ensure food security, and enhance resource use efficiency and ecosystem services. However, conventional agricultural practices have resulted in loss of diversity, soil degradation, atmospheric emissions of greenhouse gases, and water quality problems. On a more positive note, organic bio-intensive and agro-ecological farming systems offer a beacon of hope, supporting more significant natural resource conservation, improved rural livelihoods, greater diversity of farm income and farm-sector stability, and national security interests. In this context, the principles of conversion of conventional farming systems to these promising organic bio-intensive and agro-ecological farming systems, including the distinct transition periods and their roles toward sustainable and resilient food systems, were analyzed and contrasted.

Keywords: *Conversion process, conventional agricultural practices*, *food security*, *and resilient food systems*

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1. Introduction

The term "farming system" refers to the way farms and landscapes are used and how they produce agricultural products. Additionally, it can also refer to a research and development strategy that involves a multidisciplinary process of diagnosing, analyzing, testing, and scaling to enhance farming systems (Dixon et al., 2023). The farming system, which encompasses soil, plants, animals, implements, power, labor, money, and other inputs, is greatly impacted by farming families (Mahapatra, 1992). The families, who are central to the operation, have a vital and influential role in managing this system. Their impact is additionally molded by political, economic, institutional, and social forces that function at different levels. The agricultural system is a comprehensive framework that includes the elements of soil, water, crops, livestock, labor, capital, energy, and other resources. The farm family is essential and irreplaceable in this system. A farming system is a method used to define a farm's approach, encompassing the concept of agriculture having multiple functions. This is achieved through a variety of farm activities, influenced by various factors (Keating & McCown, 2001; Van de Steeg et al., 2010). In addition, the farming system, as explained by Mahapatra (1992), is neither a fixed nor unchanging thing. The system is a dynamic and intricate interconnected network of soil, plants, animals, tools, energy, labor, money, and other resources. Farming families play a role in managing the complexity, which is also affected to different extents by political, economic, institutional, and social factors operating at various levels. The ever-changing nature of the farming system emphasizes the urgent requirement for adaptability and change, creating a sense of immediacy in the audience.

The agricultural system is the result of intricate interconnections among multiple interrelated components. An individual farmer assigns specific quantities and qualities of four factors of production, namely land (the physical space for far ming), labor (the human effort involved in farming), capital (the financial resources for farming), and management (the decision-making and planning involved in farming), to which he has access (Mahapatra, 1994). The household, its resources, and the resource flows and interactions at the individual farm levels are referred to as a farm system (FAO, 2001). These resource flows and interactions which refer to the movement and exchange of resources such as labor, capital, and knowledge within the farm system, are crucial for its functioning. Given the exponential growth of the global population, escalating need for water resources, and heightened susceptibility to extreme climate events, it is imperative to reconsider the concept of food security and develop robust food systems. Additionally, it is crucial to bolster economic prospects for rural communities and foster a salubrious environment for humanity. The relentless development of population and economic expansion has ultimately led to a diminished resource foundation for future agricultural activities. Given the circumstances, there is an increasing demand for additional agricultural land and water resources, as well as a pressing need for effective management of existing natural resources. Within this particular setting, the farming system offers a comprehensive strategy that is acknowledged for its capacity to effectively manage resources and accomplish the Sustainable Development Goals (SDGs).

Rajbhandari and Gautam (1998) have firmly demonstrated that the organic bio-intensive farming system (BIFS) is not merely a theoretical concept, but a verified and effective practice. It is a comprehensive system for sustainably managing natural resources in a specific agroecosystem, based on a particular cultural and knowledge foundation. The Organic-BIFS technique, which is based on scientific principles, regularly achieves high crop yields while preserving soil fertility. This approach not only optimizes crop production but also significantly decreases the farmer's dependence on costly chemical inputs, ensuring economic stability in the midst of unpredictable markets (Thapa & Rajbhandari, 2005).The Organic-BIFS is regarded as a sustainable agricultural technique that aims to optimize crop production on limited land while also promoting biodiversity and maintaining soil fertility (Rajbhandari, 2017; Folnović, 2024).This approach prioritizes the utilization of fundamental components necessary for life, such as soil, water, air, and sun, in order to attain optimal productivity (Rajbhandari, 2017).

An Organic-BIFS has been identified as a beneficial approach for promoting sustainable agriculture and rural development (SARD) (Thapa & Rajbhandari, 2005). The Organic-BIFS adheres to the concepts outlined by Rajbhandari (2000), which include scientific crop rotation, mixed farming systems, and optimization of organic recycling.

• Collaborative research and extension

• Effective and long-lasting management of natural resources, including biodiversity, with the active involvement of all stakeholders.

• Achieving a significant level of self-sufficiency for farming households to withstand external technological and economic disruptions.

Agro-ecology is an established method for impoverished farmers in rural areas to improve the efficiency of small-scale farming systems and promote environmental sustainability (Sevilla-Guzmán & Pérez, 1976; Gliessman, 1990; Altieri, 1999; Altieri, 2002). According to the Food and Agriculture Organization (FAO, 2018), agro-ecology is the use of ecological concepts and principles to enhance the interactions between plants, animals, humans, and the environment. It also takes into account the social components that need to be considered in order to create a food system that is both sustainable and equitable. Agro-ecology can enhance food production, food security, and nutrition by creating synergies and simultaneously restoring ecosystem services and biodiversity, which are crucial for sustainable agriculture. Agro-ecology plays a crucial role in enhancing resilience and facilitating adaptation to climate change. Agroecological management practices, which are based on ecological principles, are increasingly being adopted globally in different crops and regions (Lovell et al., 2010). This approach to agriculture can provide advantages to rural communities by focusing on the local population, their knowledge, and their native natural resources (Altieri & Nicholls, 2017). Agro-ecology promotes sustainable development by emphasizing key principles such as equity, fairness, and food justice. It aims to generate new knowledge that benefits smallholder farmers and their communities (Bruil & Milgroom, 2016; Gliessman, 2018a). This strategy, as described by Gliessman (2017), focuses on prioritizing the needs and well-being of individuals. By adopting this approach, agricultural systems can become more resilient, as highlighted by Gliessman (2018b). Ecologically-based agricultural systems offer an alternative to the globalized food systems. These systems can promote employment, economic growth, and social fairness in rural economies (Delgado, 2010; Africano & Collado, 2017; Coccia, 2017;

Coccia, 2019). Furthermore, agro-ecology plays a pivotal function in bolstering biodiversity, managing water resources, and preserving forests (Wojkowski, 2004; Gliessman, 2016). Agroecological systems typically maintain consistent levels of production per unit area and generate economically advantageous returns that support the livelihoods of small farmers and their families. These systems also prioritize soil protection and the preservation of biodiversity (Altieri & Nicholls, 2017). Agroecological systems also promote on-farm biodiversity and facilitate the movement of organisms between fragmented natural habitats, which are crucial for the multifunctionality, stability, and resilience of ecosystems (Tscharntke et al., 2005; Vandermeer & Perfecto, 2007; Moonen & Barberi, 2008; Liere et al., 2017). Agro-ecology is widely recognized by experts as a crucial factor in ensuring the long-term sustainability and security of food systems (Watts et al., 2005).

2. Principles of farming system conversion

When farmers start conversion from conventional farming to agro-ecological systems, there are gradual changes in soil properties, microclimatic conditions, plant diversity, and beneficial organisms. These changes lay the groundwork for improved plant health, crop productivity, and resilience (Lotter, 2003). Agro-ecosystem conversion refers to the transformation of agricultural systems towards more sustainable and ecological practices. Several writers have described this process as having three distinct phases (McRae et al., 1990).

(1) Increased efficiency in input utilization through integrated pest management or soil fertility management.

(2) Input substitution involves replacing conventional inputs with ecologically friendly alternatives such as botanical or microbial insecticides, bio-fertilizers, and other similar products.

(3) The agro-ecosystem can enhance its soil fertility, natural pest control, and crop productivity by re-designing the system or diversifying it with optimal combinations of crops and animals that promote interactions.

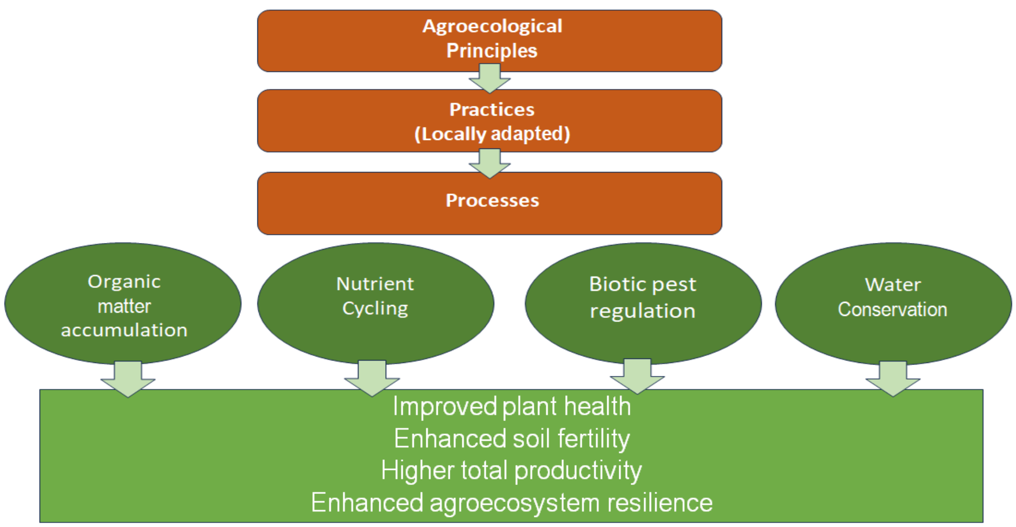

Figure 1: Agro-ecological principles for the conversion of farming systems (Adopted from Nicholls et al., 2017)

The agro-ecological principles for creating bio-diverse, energy-efficient, resource-conserving, and resilient farming systems are outlined by Altieri (1995) and Gliessman et al. (1998).

1. Improve the process of converting biomass into usable organic matter to maximize the decomposition of organic material and the cycling of nutrients over a period of time.

2. Creating suitable environments that can bolster agricultural systems' resilience by promoting functional biodiversity, including natural predators and antagonistic organisms.

3. Optimize organic matter management and encourage soil biological activity to create the most conducive soil conditions for plant growth.

4. Improving the preservation and renewal of soil and water resources, as well as agro-biodiversity, will reduce the depletion of energy, water, nutrients, and genetic resources.

5. Implement a strategy to increase the variety of species and genetic resources in the agricultural ecosystem, both in terms of time and space, at both the field and landscape levels.

6. Foster advantageous biological interactions and synergies among the elements of biodiversity, thus stimulating essential ecological processes and services.

The agroecological principles are a set of locally established practices that involve ecological interactions. These interactions are what make agroecosystems work, and they include things like recycling nutrients, keeping pests in check, building up organic matter, and keeping water from running off (Figure 1).

Each locally adopted practice is linked to one or more principles, thus contributing to its manifestation in the function of the whole agro-ecosystem (Table 1). The set of management practices that are mutually adaptive and, when acting together, used to lead to high performance is often called production syndrome. In this context, the array of cultural practices used by each farmer plays a significant role in creating functional differences, showcasing the diversity and complexity of agro-ecosystems that cannot be accounted for by any single practice.

Table 1. Relative contribution of several management practices to one or more agro-ecological principles (Vázquez LL et al., 2012)

Management Practice	Principle to which they contribute*					
	1	2	3	4	5	6
Compost application	×		×			
Cover crops and/or green manures	×	×	×	×	×	×
Mulching	×		×	×		
Crop rotation	×		×	×	×	
Use microbial/botanical pesticides		×				
Use of insectary flowers		×			×	×
Living fences		×	×		×	×
Intercropping	×	×	×	×	×	×
Agroforestry	×	×	×	×	×	×
Animal Integration	×		×	×	×	×

Note. *Each number refers to an agroecological principle.

According to Nicholls et al. (2016), agro-ecological concepts can be successfully implemented into farming systems by farmers through various tactics and procedures that support natural processes, increase productivity, and preserve the ecosystem's health. Applying compost is a technique that significantly improves soil fertility, organic matter turnover, and nutrient cycling. Green manures and cover crops aid nutrient fixation, soil preservation, and weed control. Mulching is another helpful tactic that promotes improved soil health, moisture retention, and weed suppression. Crop rotation is an essential technique that promotes improved soil health, nutrient cycling, and insect control. Microbial and botanical pesticides reduce the need for artificial chemicals by encouraging natural pest control. The presence of beneficial insects, drawn to insect-based flowers for pollination and pest control purposes, further underscores the ecological balance in agro-ecological systems.

3. Transition of organic bio-intensive farming system (BIFS) and agro-ecology

The principles mentioned above and ideas can be applied to conversion by the following process:

Process 1: According to Rajbhandari (2017), the conversion of the farming system from conventional (petrochemical) management to organic bio-intensive management is a transitional process consisting of three marked phases:

1. Progressive withdrawal of toxic chemical inputs: This phase involves reducing the use of toxic chemical inputs such as chemical fertilizers, pesticides, and other petrochemicals that are scarce, costly, and environmentally damaging. Integrated Soil Fertility Management (ISFM) and Integrated Organic Pest Management (IOPM) accomplish this by rationalizing the use of petrochemicals and organic inputs.

2. Input substitution: This phase entails substituting conventional (external high input) technologies with alternative (local low input) technologies, such as organic manure, bio-fertilizers, or inoculums.

3. This phase entails re-designing the farming system for optimal integration of crop/livestock/agro-forestry/fishery to function in a new set of ecological processes.

Process 2: Five distinct levels comprise the transition to sustainability in agro-ecology. The conversion of the farming system from conventional (petrochemical) management to agro-ecological management is a transitional process consisting of five marked levels. According to Gliessman (2015), agro-ecological transformation can be understood as having five levels:

1. Enhance the efficacy of industrial and conventional methods: This stage entails improving the effectiveness of industrial and conventional techniques to minimize the utilization and depletion of expensive, limited, or environmentally harmful resources.

2. Implement alternative practices: This stage entails replacing industrial or conventional inputs and procedures with alternative methods.

3. Revamp the agro-ecosystem: This stage entails overhauling the agro-ecosystem to operate according to a fresh array of ecological processes.

4. Re-establish a more direct connection: This level involves re-establishing a more direct connection between those who grow the food and those who consume it.

5. Construct a novel global food system: This stage entails constructing a fresh global food system that is founded on principles of fairness, involvement, and fairness. This system should not only be environmentally sustainable but also contribute to the rehabilitation and preservation of the earth's life-support systems.

Table 2. A comparison between the conversion of a conventional farming system to an organic-BIFS (bio-intensive farming system) and the transition to sustainability in agro-ecology

Process 1: Conversion to Organic-BIFS	**Process 2: Transition to Sustainability in Agro-ecology**
Conversion process has 3 Phases	Conversion process has 5 Levels
The process focuses on organic bio-intensive management	The process focuses on agro ecological management
Toxic Chemical Inputs are progressively withdrawn	Increase efficiency and reduction of inputs
Input substitution are done with organic inputs	Substituted with alternative practices
In this Farming System Optimum integration of systems is sought after	In this Farming System re-design for new ecological processes
Does not have direct connection between growers and consumers	Re-establish direct connection between growers and consumers
Does not directly refer to new global food system based on equity and sustainability	Build a new global food system based on equity and sustainability

Changing farming systems from conventional (petrochemical) management to Organic-BIFS and moving toward sustainability in agro-ecology are two separate processes that aim to change farming methods from conventional and industrial ones to ones that are more sustainable and beneficial for the environment. In order to convert to Organic-BIFS, the primary objectives are to use less harmful chemical inputs, replace outdated technologies with more eco-friendly ones, and re-design the farming system to integrate crops, livestock, agro-forestry, and fisheries as best as possible into a new ecosystem.

The shift towards sustainability in agro-ecology focuses on improving the effectiveness of traditional and industrial methods. This involves replacing conventional and industrial inputs and practices with alternative ones, reorganizing the agro-ecosystem to operate based on new ecological processes, re-establishing a closer connection between food producers and consumers, and establishing a new global food system that is based on principles of fairness, equality, and participation. Such a system not only ensures sustainability but also contributes to the protection and restoration of the Earth's life-support systems. There are some differences between Organic- BIFS conversion and the transition to sustainability in the agro-ecological farming system.

This table 2 highlights the contrast between the two processes in terms of their phases, focus, approach to chemical inputs, input substitution, farming system re-design, connection between growers and consumers, and the vision for a global food system.

4. Pathways toward sustainable agriculture and food system

Agro-ecological farms, in contrast to conventional agricultural systems, play a crucial role in agro-biodiversity and sustainable environmental management in rural areas (Figure 2). These farming systems have a significantly higher impact on stabilizing and diversifying small farmers' income, offering improved working conditions and more leisure time. They also excel in sustainable forest and natural resources management, outperforming conventional farming systems. Notably, the sustainability of agro ecology is particularly advantageous for small-farming system.

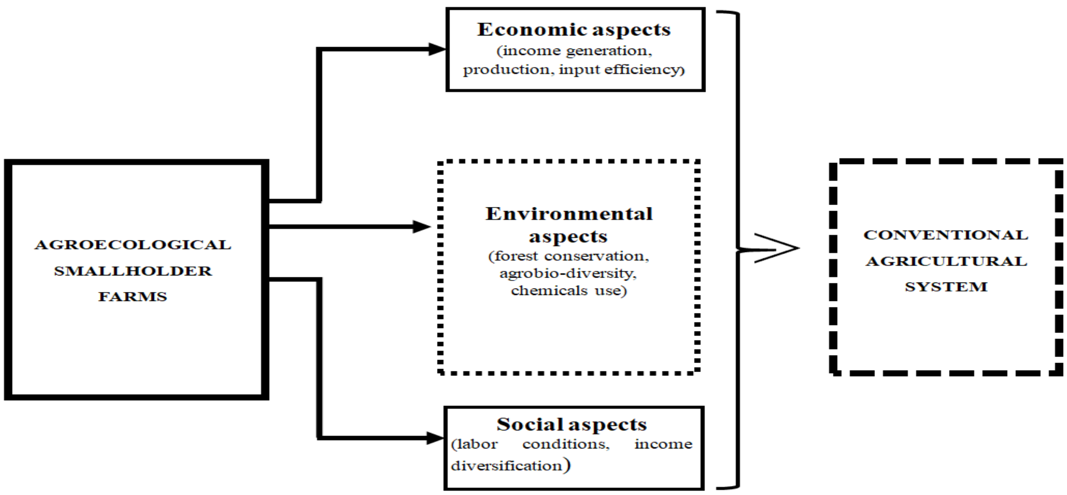

Figure 2. Model of induced-sociological benefits of agro ecological systems in rural areas (Adapted from Pronti & Coccia, 2020)

According to Rana and Chopra, (2013), conversion and transition to sustainability of agro-ecology involves several key steps and considerations:

1. Transition to sustainable agriculture: The primary objective of transitioning to sustainable agriculture is to establish efficient and profitable farming systems that prioritize the conservation of natural resources, protection of the environment, and improvement of long-term health and safety. This transition entails shifting from current farming practices, which sometimes largely depend on chemical inputs, to more holistic and environmentally sustainable approaches.

2. Low-input sustainable agriculture (LISA): It is a suggested agricultural system aimed at achieving sustainability. LISA relies on minimal external production inputs, resulting in lower production costs, reduced hazards for farmers, and contamination prevention. Nevertheless, in light of growing population pressure, it is imperative to tackle difficulties such as low agricultural yields. LISA is an agricultural system designed to minimize the reliance on external inputs, such as fertilizers and pesticides, by utilizing natural processes and resources to sustain soil fertility and manage pests.

3. Organic farming and waste recycling: Organic farming is the backbone of sustainable agriculture. Sustainable agriculture relies on organic recycling, which minimizes or eliminates the use of industrial agricultural chemicals. Organic recyclable waste, such as crop residues and farm industrial waste, is an excellent source of plant nutrients and contributes to sustainable farming practices.

4. Integrated farming system: It plays a crucial role in environmental sustainability. Nothing goes to waste when livestock and crop production are integrated, and the by-products of one system become inputs for another. This approach helps small farmers diversify their production, increase income, and improve food quality while utilizing resources efficiently. Integrated farming systems not only maximize resource use and waste reduction, but they also promote biodiversity and reduce the environmental impact of agriculture.

5. Regenerative agriculture: Regenerative agriculture focuses on enhancing the regeneration of renewable resources to achieve sustainable agriculture. It emphasizes the importance of regenerating resources for long-term agricultural viability and addressing economic and social concerns.

6. Whole farm planning: Whole farm planning provides farmers with management tools to manage complex farming systems profitably. It encourages setting explicit goals, assessing resources, and adopting sustainable practices to ensure the farm's long-term viability.

The following aspects of Organic-BIFS support the ideas of sustainable agriculture:

1. Maximizing yields: Compared to conventional agriculture, bi-ointensive farming seeks to create large crop yields while consuming less land, water, and energy. This makes it resource-efficient and environmentally friendly (Rajbhandari, 2017).

2. Increasing biodiversity: Bio-intensive agriculture plays a crucial role in enhancing biodiversity within farming systems. Promoting companion planting, deep soil preparation, and carbon farming contributes significantly to ecosystem health and resilience (Slavikova, 2017), making the audience feel more environmentally conscious.

3. Sustaining soil fertility: Through practices like double digging, on-site composting, and minimal use of machinery, bio-intensive farming focuses on maintaining healthy soils, which is crucial for long-term agricultural sustainability (Rajbhandari, 2017; Folnović, 2024).

4. Reducing resource use: Bio-intensive farming uses significantly less land, water, fertilizer, and energy than conventional agriculture, making it a more sustainable and environmentally friendly approach to food production (Rajbhandari, 2017; Folnović, 2024).

According to Lwayo and Maritim (2003), social and economic factors are the primary drivers for changes in attitudes and skills toward adopting farming system components. Alavalapati et al. (1995) state that the adoption process is a cognitive process that is directly impacted by social and economic circumstances. Examining the interplay between socio-economic and bio-physical processes aids small-scale farmers in making informed decisions (Matata et al., 2010; Baffoe-Asare et al., 2013). According to Obeng and Weber (2014), a farmer's decision to adopt is influenced by social and economic reasons. According to a collaborative proposal by Owubah et al. (2001), farmers' inclination to adopt an agricultural component is mostly determined by its significance, which can be measured in terms of its potential economic gains, contribution to food security, or environmental advantages.

Although the initial expense of setting up the ecological infrastructure for an integrated farm is often significant in the first 3-5 years (Altieri et al., 2012), the future advantages are encouraging. When the rotation and other vegetation designs, such as cover crops, polycultures, and field boundaries, begin to offer ecological services to the farm, crucial ecological processes are initiated. As a result, there is a notable reduction in the requirement for external inputs and maintenance expenses, since the farm's functional biodiversity supports natural activities like as nutrient cycling and pest regulation. Farmers experience a reduced frequency of weeding and fertilizing their crops, providing them with a substantial respite from their typical workload. Over time, the need on external inputs diminishes as biodiverse farms, specifically developed for this purpose, support their own functioning (Nicholls et al., 2016). The transition involves shifting from a capital-intensive and input-dependent form of agriculture to a process-based approach, which offers the potential for more sustainable and economically efficient farming methods.

The various methods and approaches in agro-ecology, such as permaculture, agroforestry, conservation agriculture, and organic farming, aim to promote the principles of agro-ecology by improving the efficient use of resources, which is crucial for sustainable farming. These methods also enhance the ability of agricultural systems to withstand and recover from disturbances, while ensuring fairness and accountability in a secure manner (Chaudhary et al., 2023). The utilization of asexual propagation methods, such as budding and grafting, in the organic farming system of fruit crops has shown potential in enhancing the yield, disease resistance, and overall productivity of the orchards. (Rai & Rai, 2024a; Rai & Rai, 2024c). The adoption of farming practices to mitigate the Monkey Menace, which is a widespread problem in South Asia and Southeast Asia, plays a crucial role in determining the sustainability of the food system (Rai & Rai, 2024b). Moreover, the study of the farming system has a pivotal impact on improving agricultural production, sustainability, and the livelihood of smallholder farmers in Nepal (Shrestha et al., 2024). The future food system will exhibit enhanced resilience, democracy, and sustainability in order to nourish an expanding population while mitigating the detrimental environmental impacts of agriculture. The future food system is expected to undergo substantial changes to tackle the challenges of nutrition, food security, and sustainability. These changes will involve a greater focus on plant-based diets, sustainable agriculture, precision farming, technology, vertical and urban farming, reduced food waste, improved supply chains, sustainable fisheries and aquaculture, food system resilience, climate adaptation, enhanced food traceability and transparency, and localized and community-centered food systems (Chaudhary et al., 2023).

5. Conclusions

In conclusion, the transition to sustainability in agriculture is a crucial goal shared by organic bio-intensive farming systems (BIFS) and ecologically based farming systems. While both approaches aim to replace industrial or conventional farming practices with more sustainable and ecological ones, their focus and priorities differ. The conversion to Organic-BIFS emphasizes reducing hazardous chemical inputs, adopting alternative technologies, and reorganizing the farming system to maximize the integration of crops, livestock, agro-forestry, and fisheries. This re-design aims to establish a new set of ecological processes, reconnect food producers and consumers, and create a more equitable global food system. On the other hand, agro-ecology focuses on re-designing the agro-ecosystem to function on ecological principles, promoting resource efficiency, and ensuring long-term viability. The importance of these ecological principles cannot be overstated, as other hand; agro-ecology focuses on re-designing the agro-ecosystem to function on ecological principles, promoting rest hey inspire farmers to contribute to a sustainable agriculture system that is environmentally friendly, economically viable, and socially just.

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