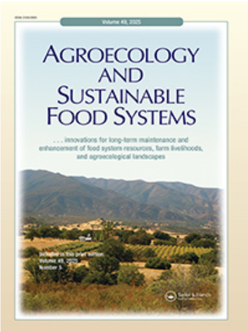

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Agroecology and Sustainable Food Systems

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/wjsa21

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To cite this article: Mohammad Selim Reza, Naznin Sultana, Selene Murillo Vega & Gabriela Sabau (15 Mar 2025): Agroecology: the science and art of building sustainable agri-food systems. A case study from Costa Rica, Agroecology and Sustainable Food Systems, DOI: 10.1080/21683565.2025.2476176

To link to this article: https://doi.org/10.1080/21683565.2025.2476176

Published online: 15 Mar 2025.

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS
https://doi.org/10.1080/21683565.2025.2476176

Agroecology: the science and art of building sustainable agri-food systems. A case study from Costa Rica

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ABSTRACT

The process of change taking place in most countries' agricultural and food systems has seen a revival of alternative forms of farming, like agroecology, aiming to replace the environmentally destructive practices of conventional agriculture and produce real and nutritious food. This case study analyzes the process of transition of a small-scale farm located in Costa Rica from conventional farming (using heavy machinery, synthetic chemicals, and fossil fuels) to a carefully integrated, resilient, sustainable and self-sustaining organic, agro-socio-ecological system. It uses UN FAO's (Food and Agricultural Organization of the United Nations) Tool for Agroecology Performance Evaluation (TAPE) with 10 agroecological elements (diversity, synergies, efficiency, recycling, resilience, culture and food traditions, co-creation and sharing of knowledge, human and social values, circular and solidarity economy, and responsible governance) to assess the farm's ecological, social and economic performance. Results show that this farm is strong in efficiency, culture and food tradition, co-creation and sharing of knowledge, diversity, and resilience. The average score of the 10 elements is 92.29%, indicating an advanced level of transition to agroecology of the farm. While this score is high, the farm has encountered certain challenges, namely lack of consistent financial and policy support from the government, costly procedures for products and processes certification, and lack of awareness about the benefits of this sustainable farming system. The study recommends that more transdisciplinary research and comparative studies between conventional and agroecological farming are needed to move more agrifood systems toward sustainability.

KEYWORDS
Agroecology; integrated farming; sustainability transition; sustainable development goals; FAO; TAPE; Costa Rica

SUSTAINABLE DEVELOPMENT GOALS
SDG 2: Zero hunger; SDG 3: Good health and well-being; SDG 12: Responsible consumption and production; SDG 13: Climate action; SDG 15: Life on land

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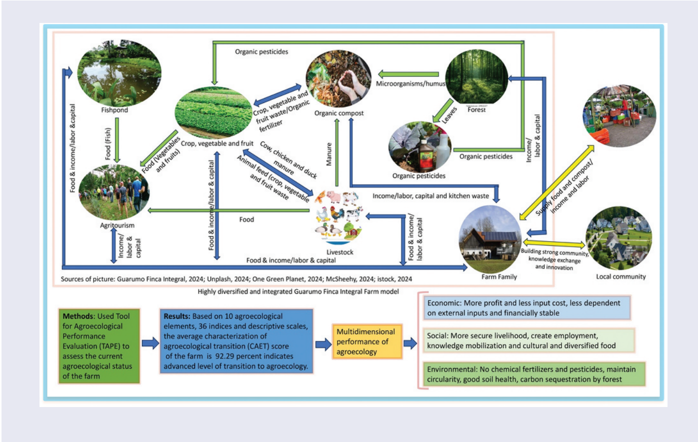

1. Introduction

There is a process of change occurring in most countries' agricultural and food systems due to a growing understanding of the fact that the environment, agriculture, and human health are closely interrelated. This process of change, which started in the 1980s, has seen a revival of alternative forms of farming such as biodynamics, agroecological, organic, regenerative, conservation, permaculture, agroforestry, and holistic. These aim to replace the environmentally destructive practices of conventional agriculture by producing real, nutritious food, and by securing the livelihoods of farmers (IUCN 2020; Muhie 2022). These goals are elements of sustainable agriculture that can preserve life and the life-sustaining systems we find in nature (Sabau 2024). Agroecological-type practices for sustainable use of soils and food production have existed for thousands of years in thriving Indigenous and peasant societies on all continents (Pimbert et al. 2021a). At the beginning of the 20th century, agronomy scientists began to use ecological principles in agriculture and food production (FAO 2019; Gliessman 1990; Pimbert et al. 2021b; Rosado-May 2015).

Knowing that there is wisdom in the functioning of nature that can be mimicked in human-made systems, agroecology has been defined "the application of ecological concepts and principles to the design and management of sustainable agroecosystems, or the science of sustainable agriculture" (Altieri 1995; Caporali 2007; Gliessman 2018, 599). Some argue that agroecology is more than a science (Galt et al. 2024; Wezel et al. 2009). Wezel et al. (2009, 2020) and Varghese (2022) characterize agroecology as a scientific discipline, a set of agricultural practices and as a political or social movement. As a scientific field, agroecology follows a transdisciplinary approach, as the knowledge of agroecology integrates academic knowledge from natural sciences, social sciences and humanities with people's knowledge, farmers' practices, insights from Indigenous management systems and local institutions, through various "dialogues of knowledges" (Carlile and Garnett 2021; Pimbert et al. 2021a).

As an agricultural practice, agroecology promotes diversity in farm structure and management, through such actions as ecologically-based rotations, multiple cropping, agroforestry, and the integration of animal husbandry with crop cultivation (Barrios et al. 2020; Gliessman 2016; Singh et al. 2024). Maintenance of functional diversity is of high ecological importance influencing several aspects of agroecosystems' functioning such as pest control, nutrient cycling, organic matter decomposition, yields, and resilience (Pimbert et al. 2021a). Small-scale farms "permit the development of functional biodiversity with diversified production and the integration of crops, trees and livestock. In this type of agriculture, there is less or no need for external inputs, as everything can be produced on the farm itself" (Galli, Cavicchi, and Brunori 2019; Giller et al. 2021; LVC 2010).

Agroecology was promoted by environmental movements aiming to protect nature from the assault of industrial agriculture in the 1970's, and by social movements for rural development, such as La Via Campesina (LVC), in the 1990's. Established in 1993, LVC is an international peasant movement which encompasses 182 local and national organizations in 81 countries across Africa, Asia, Europe, and the Americas (Rosset and Martínez-Torres 2012). Agroecology is at the heart of LVC, but is defined more broadly than just ecologically-based production principles, as it also "incorporates social, cultural and political principles and goals" (Rosset and Martínez-Torres 2012). One of the important goals of the agroecological movement is to achieve food sovereignty for peasant farmers, by putting "the aspirations and needs of those who produce, distribute, and consume food at the heart of food systems and policies, rather than the demands of markets and corporations" (Gliessman, Friedmann, and Howard 2019; Laforge et al. 2021; Nyéléni 2007). Since 2014, the United Nations' Food and Agricultural Organization (FAO) has promoted agroecology, redefined as the "ecology of the food systems" (Francis et al. 2003), for its potential to solve in a sustainable way the global problem of food security and to contribute directly to the implementation of multiple UN Sustainable Development Goals, namely goals 2, 3, 12, 13, and 15.

The FAO has organized two international symposia and numerous expert workshops and forums on agroecology and has developed various tools to help countries operationalize agroecology in their national agriculture and food systems (FAO 2018, 2019). While there is a growing understanding that agroecology practices and philosophies are working with nature and not against it, agroecology needs to find its way into national legislations, policies, and institutions in order to make agri-food systems sustainable (FAO 2024b). However, very few steps are being taken to make agroecology mainstream in both developed and developing countries. There are few studies which demonstrate empirically that sustainable agriculture on small-scale farms is feasible and can contribute to reducing poverty in developing countries, while protecting the environment and feeding the world (Galli, Cavicchi, and Brunori 2019; Hazell 2015; Pretty, Bragg, and Hine 2002; Woodhill, Hasnain, and Griffith 2020). That is why more evidence is needed to change minds and policies concerning sustainable agriculture, as oversimplified narratives about how small-scale farmers practicing agroecology can be sustainable "are hampering sound policy making and public investment" (Woodhill, Hasnain, and Griffith 2020).

In fact, greater diversity of traditional crops increases food nutritional value, and can lead to market diversification and mitigation of drought risk (Keleman et al. 2013). Moreover, the smaller farms harbor a higher level of non-crop biodiversity due to limited pesticide use and use of organic fertilizers, as well as increase field edges, which lead to larger available breeding habitats for arthropods, an increased number of pollinators, beneficial predators within fields, and improved land composition by adding forests and wetlands (Lovell et al. 2010; Pekin 2016).

At the global level, it is also the small-scale farms that feed the world. A study by Lowder, Sánchez, and Bertini (2021) has found that around 84% of all farms worldwide are small-scale and operate on around 12% of the agricultural land. They also supply roughly 35% of the world's food. Ricciardi et al. (2021) analyzed the relationship between farm size and production, profitability, resource-use efficiency, biodiversity and greenhouse gas emissions, and found that smaller farms have higher yields (in either weight/ha and value/ha) and foster "greater crop diversity and higher levels of non-crop biodiversity at the field and landscape scales than larger farms." Belfrage, Björklund, and Salomonsson (2005) and Liebert et al. (2022) argued that policymakers, scholars, and social movements should emphasize land reform to redistribute farmland (Borras, Edelman, and Kay 2008; Rosset 2013), as small-scale farms perform better in terms of production, socio-economic outcomes and environmental protection than large-scale farms.

This study analyzes the evolution of a small-scale farm located in Sarapiqui, Costa Rica from conventional farming into a carefully integrated, resilient and self-sustaining organic, agro-socio-ecological system. There are several reasons for choosing this farm. The first reason is the well-known fact that Costa Rica is one of the most biologically diverse countries in the world (hosting about 5% of the world biodiversity), with strong environmental policies and a long-standing National System of Conservation Areas (SINAC), initiated in the 1970s and covering now about 28% of the national territory (Jordan 2022). According to a recent FAO report, "Costa Rica is among the global leaders in responding to climate change, with a long history of environment protection, sustainable development, and action on climate change mitigation" (FAO 2024b). The second reason is the country's interest in developing sustainable agricultural practices, as seen in Costa Rica's National Climate Change Adaptation Policy (2018–2030) which sets priorities in the area, namely: "(i) the promotion of adaptation based on ecosystems outside the state's natural heritage, through the conservation of biodiversity in biological corridors, private reserves, and farms under forest regime; and (ii) the promotion of water security in the face of climate change, through the protection and monitoring of sources and proper management of hydrological basins" (FAO 2024b). The third reason is related to the effective outcomes of the agroecological model of integrated farms in Costa Rica, a model aiming to produce healthy food while preserving the integrity of the natural environment by adopting environmentally friendly agricultural practices which maximize the use of natural resources, such as energy, water, and soil (Jiménez 2001, 2021, 2023). There are about 200 integrated farms in Costa Rica, where most of them are medium and small-scale, and highly diversified. According to Jiménez and Ulate Segura (2023), the system of integrated farms in Costa Rica, "has the potential to guarantee food sovereignty and food security for the national population, at least partially." All these medium and small-scale farms produce food and participate in local food markets, thus solving the problem of self-consumption (Jiménez and Ulate Segura 2023).

This study uses empirical data and the FAO's Tool for Agroecology Performance Evaluation (TAPE) to demonstrate sustainability at the small-scale integrated farm level, where the principles of agroecology complement the goals of food sovereignty (FAO 2024a). On this farm, agroecological practices break the farm's dependence on outside inputs by using diverse agro-ecosystem services for soil health, biodiversity, pest control, land productivity, and nutritional diversity. This integrated farm became sustainable through the careful design and hard work of the farm owners and is now sustainable not only ecologically but also economically and socially, being able to secure the wellbeing and beauty of natural ecosystems, of the family members, and of the local community.

Studies show the need for more research about the characteristics of farms engaged in sustainable agriculture. This case study provides primary information about sustainable farming on a small-scale, diversified and integrated agroecological farm, which is a model that can be implemented on other farms globally to increase organic food production, protect the farm's ecosystems, and enhance food and livelihood security for the farmers. The aim of this paper is to make government bodies aware of the need for structural change in agrifood systems, which can become sustainable by considering the potential of agroecology science, thinking, and practices.

The paper is structured as follows: (1) the introduction, which also includes a literature review; (2) research methodology, which covers farm selection, data collection and data analysis; (3) empirical results based on data analysis; (4) a critical discussion of the results; and (5) concluding thoughts and policy recommendations.

2. Research methodology

2.1. Farm selection

In this research, La Finca Integral El Guarumo (The Farm, thereafter) was chosen as a case study. It is a small-scale and highly integrated agroecological farm located in Horquetas de Sarapiquí, Costa Rica. The Farm has been owned and operated since 1979 by a Costa Rican family, a man, his wife and their children. The daughter and one son of the farm owner are involved part-time in the operation of the farm. This small-scale and self-dependent farm integrates crops, livestock, aquaculture, agroforestry, and agritourism. The farm collaborates with local and international universities, training centers, government departments, and the local community. The total size of the farm is 10 hectares, out of which 78.4% is dedicated to productive activities, 6.8% is covered by built structures, 3.7% is a river ravine, and 11.2% is washed by the San Jose River (Jiménez and Avellán Zumbado 2012).

2.2. Data collection

This study uses a mixed research method, by analyzing both secondary data and primary data, collected from interviews over video calls. We interviewed six key Costa Rican respondents, who are directly involved in this farm either for farming activities or for research purposes. The primary data (both quantitative and qualitative) were collected during May to June 2024. The interview questions focused on land distribution, farm integration, variety of crops, vegetables and fruits grown on the farm, details about raising livestock and fish-farming. The interviews also covered topics such as reintroducing the forest on the farm, as well as home production of organic fertilizers, pesticides, and biogas, food processing and marketing, government and institutional support, and collaboration with other farmers and stakeholders. In addition to the online interviews, the researchers emailed the farmers. One of the researchers visited the farm in April 2024 and discussed with the farmer and his family members about their farming practices. The secondary data and pictures were collected through reviewing the farm website, the Facebook page of the farm, several books, published articles, government reports, and newspaper articles. Among the key words used for the literature review were agroecology, sustainable agriculture, small-scale farms, integrated farming, organic farming, and ecological efficiency. In addition, Professor Wilberth Jiménez Marín and María José Avellán Zumbado have done a case study on this farm in 2012. Their study is used as a secondary data source in this current study with their permission.

2.3. Data analysis

To measure the multi-dimensional performance of agroecological systems and to assess the level of agroecological transition of a small-scale farm across different dimensions of sustainability, this study used the global analytical framework of agroecology called Tool for Agroecology Performance Evaluation (TAPE) (FAO 2024a). The tool follows a stepwise approach which includes four steps. Step 0, conducted at a community or territorial level, including farm and household levels, provides a preliminary description of the production systems, type of household, agroecological zones, and existing policies, including climate change. Step 1 is a tool for characterizing the level of transition to agroecology of productive units (farms, households, or community), based on FAO's proposed 10 Elements of Agroecology (FAO 2019) (Figure 1). Step 2 consists of a short list of core performance criteria needed to evaluate the multidimensional performance of the farming unit.

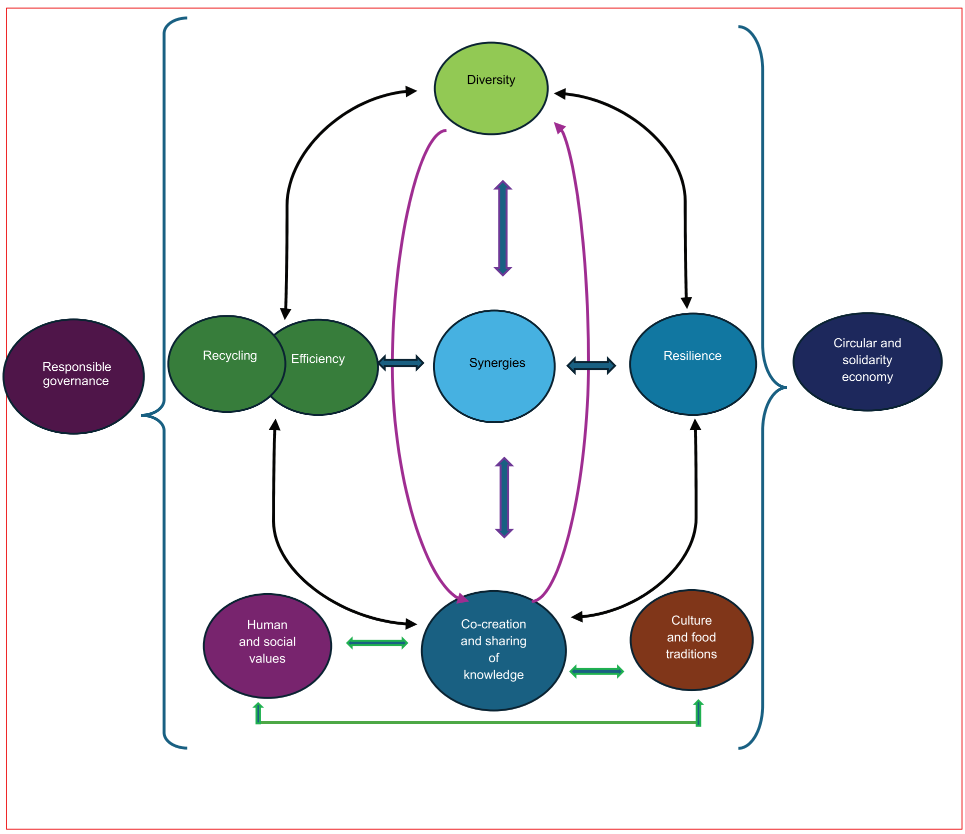

Figure 1. The 10 elements of agroecology: guiding the transition to sustainable food and agricultural systems. Source: FAO (2018); Figure: Researchers' drawing (2024)

Step 3 is an analysis of the results obtained in the previous steps, and a participatory interpretation of this analysis.

The 10 elements of agroecology are diversity, synergies, efficiency, recycling, resilience, culture and food traditions, co-creation of knowledge, human and social values, circular and solidarity economy, and responsible governance (FAO 2018; Wezel et al. 2020). They have been used as criteria to define semi-quantitative indices that take the form of descriptive scales with scores from 0 to 4 (a modified Likert-type scale). For example, the relevant indices of the element "Diversity" are (i) Diversity of crops, (ii) Diversity of animals, (iii) Diversity of trees, and (iv) Diversity of activities, products and services. The score of the first index (diversity of crops) of the diversity element ranges from 0 to 4, depending on diversified crop production. If the farm practices monoculture or cultivates no crops, then the value of the first index is 0. The score of the first index will be 1, if the farm cultivates one crop covering more than 80% of the cultivated area. When the farm produces two or three crops on a significant cultivated area, the score will be 2. We can assign a score of 3 when the farm produces more than 3 crops with a significant cultivated area adapted to local and changing climatic conditions. The farm will receive the highest value 4, when it produces more than 3 crops of different varieties adapted to local conditions and is a spatially diversified farm with multi-, poly- or inter-cropping. The scores of the indices of the other elements are calculated depending on the farm practices and their relationship with other stakeholders, and following the FAO guidelines.

The assigned scores of the four indices are summed up (for example $2 + 3 + 3 + 4 = 12$) and the totals are standardized on a scale from 0 to 100% ($12/16 \times 100 = 75\%$) to obtain the general score for the element "Diversity." Using the same procedure, this study calculated the average score of the remaining 9 agroecological elements to define relevant ranges for each category. For example, scores <50% show non-agroecological systems (that may be market oriented conventional agriculture, as well as subsistence level), scores from 50 to 70% show farms in transition to agroecology, while scores > 70% show advanced agroecological systems (FAO 2019). The total number of indices to be scored in the Characterization of Agroecological Transition (CAET) is 36 (FAO 2019). The results of the first step can be visualized in a spider diagram that supports self- and peer-reflection and can inform discussions on how to advance in the agroecological transition of the evaluated system. While no prescriptive threshold is defined, systems with high scores across all 10 elements are considered well-advanced in the agroecological transition. This research used Microsoft Excel to calculate the average score of the elements and draw the spider diagram for this farm.

3. Results

According to the FAO definition, "Agroecology is a holistic and integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of sustainable agriculture and food systems. It seeks to optimize the interactions between plants, animals, humans, and the environment while also addressing the need for socially equitable food systems within which people can exercise choice over what they eat and how and where it is produced" (FAO 2024a). In 2018, the FAO proposed the framework of 10 elements of agroecology for characterizing the agroecological transition toward the sustainability of agriculture and food systems. Among the 10 agroecological elements, each of 6 elements has 4 indices, and the remaining 4 elements have 3 indices that measure the level of agroecological transition (Table 1).

Table 2 shows the descriptive scales and scores of each index of the Diversity element of agroecology. There are five descriptive scales of each index, and the score assigned to the scales ranges from 0 to 4 indicating low agroecological performance to high performance. The score of the diversity of crops index for The Farm is 4, as the farmer produces 25 varieties of crops, vegetables and fruits. The farm also produces multiple crops on the same land and in the same season with inter-cropping or mixed cropping.

For the index of animal diversity, the assigned score is 3, since the farmer raises different species of animals, cows (7), hens (30), ducks, one turkey, one pig and one horse. Though the number of species is higher than 3, the number of animals is not too high. For the index of tree diversity, the assigned score is 4, including lumber trees, and different varieties of fruit trees, like coconut, cocoa, and orange grown on The Farm. The farmers engage in different activities on the farm, producing diversified crops and fruits, raising animals, producing organic fertilizers and pesticides, processing bananas, making chocolate and offering agri-tourism services, and, therefore, the assigned score is 4 for the diversification of activities, products and services. Based on the farmer's responses and the farm characteristics, the researchers assigned index scores for each element, and then added the scores and converted them into percentages. The results are presented in The Farm's CAET (Table 3). The assigned score for the diversity element is 15 out of 16 or 93.75%. This score indicates that The Farm is highly diversified.

For the element Synergies, The Farm practices crop-livestock-aquaculture integrated farming. The volume of fish production is very small, just for family and tourists' consumption. The farm is assessed as weaker in soil-plant management and connectivity between elements of the agroecosystem and landscape. The general score of the Synergies element is 87.5%, which is higher than 70%, meaning that the farm displays an advanced level of synergies. As

Table 1. Agroecological elements and indices of each element.

Elements	Indices			
Diversity	Diversity of crops	Diversity of animals (including fish and insects)	Diversity of trees (and other perennials)	Diversity of activities, products and services
Synergies	Crop-livestock-aquaculture integration	Soil-plants system management	Integration with trees (agroforestry, silvopastoralism, agrosilvopastoralism)	Connectivity between elements of the agroecosystem and the landscape
Efficiency	Use of external inputs	Management of soil fertility	Management of pests & diseases	Productivity and household's needs
Recycling	Recycling of biomass and nutrients	Water saving	Management of seeds and breeds	Renewable energy use and production
Resilience	Stability of income/ production and capacity to recover from perturbations	Mechanisms to reduce vulnerability	Indebtedness	Diversity of activities, products and services
Culture & Food Traditions	Appropriate diet and nutrition awareness	Local or traditional (peasant/ indigenous) identity and awareness	Use of local varieties/ breeds and traditional (peasant & indigenous) knowledge for food preparation	
Co-Creation & Sharing of Knowledge	Platforms for the horizontal creation and transfer of knowledge and good practices	Access to agroecological knowledge and interest of producers in agroecology	Participation of producers in networks and grassroot organizations	
Human & Social Values	Women's empowerment	Labour (productive conditions, social inequalities)	Youth empowerment and emigration	Animal welfare [if applicable]
Circular & Solidarity Economy	Products and services marketed locally	Networks of producers, relationship with consumers and presence of intermediaries	Local food system	
Responsible governance	Producers' empowerment	Producers' organizations and associations	Participation of producers in governance of land and natural resources	

Source: FAO (2019).

for the Efficiency element, The Farm is highly efficient with the general score of the Efficiency element of 100%.

The overall score of the Recycling element is 62.50%, which indicates a moderate level of recycling on The Farm has some limitations, like the fact that there is no renewable energy and no water recycling on the farm. After evaluating the four indices of the Resilience element, it was found that the general score of resilience is 93.75%. The Farm is

Table 2. Assigned values of each index in the "diversity" element of agroecology for the farm.

Elements	Index	Score	0	1	2	3	4
Diversity	Diversity of crops	4	Monoculture (or no crops cultivated).	One crop covering more than 80% of cultivated area.	Two or three crops with significant cultivated area.	More than 3 crops with significant cultivated area adapted to local and changing climatic conditions.	More than 3 crops of different varieties adapted to local conditions and spatially diversified farm with multi-, poly- or inter-cropping.
	Diversity of animals (including fish and insects)	3	No animals raised.	One species only.	Two or three species, with few animals.	More than three species with significant number of animals.	More than three species with different breeds well adapted to local and changing climatic conditions.
	Diversity of trees (and other perennials)	4	No trees (nor other perennials).	Few trees (and/or other perennials) of one species only.	Some trees (and/or other perennials) of more than one species.	Significant number of trees (and/or other perennials) of different species.	High number of trees (and/or other perennials) of different species integrated within the farmland.
	Diversity of activities, products and services	4	One productive activity only (e.g. selling one crop only).	Two or three productive activities (e.g. selling 2 crops or one crop and one type of animals).	More than 3 productive activities.	More than 3 productive activities and one service (e.g. processing products on the farm, ecotourism, transport of agricultural goods, training, etc.).	More than 3 productive activities, and several services.

Source: FAO (2019); Own calculation (2024).

Table 3. Results of the characterization of agroecological transition (CAET) for the farm.

Agroecological Elements	Score of 4 indices	(%)
Diversity	4+3+4+4=15/16	93.75
Synergies	4+3+4+3=14/16	87.5
Efficiency	4+4+4+4=16/16	100
Recycling	4+3+3+0=10/16	62.50
Resilience	4+3+4+4=15/16	93.75
Culture & Food Traditions	4+4+4=12/12	100
Co-Creation & Sharing of Knowledge	4+4+4=12/12	100
Human & Social Values	4+4+3+4=15/16	93.75
Circular & Solidarity Economy	4+4+3=11/12	91.66
Responsible Governance	4+4+4=12/12	100

Source: Own calculation (2024).

financially stable and earns sufficient money to pay all the expenses of the household and farm operation. The Farm is less vulnerable, as the farmer produces a variety of vegetables, fruits, and livestock, and if one crop/fruit fails, the loss is covered by other crops/fruits or by livestock. Offering agri-tourism services also adds some resilience to the farm's income.

The farmer respects the local culture and food traditions and is always trying to supply fresh, organic and chemical-free healthy food to the local market. (SDG:3) The general score of the Culture and Food Traditions element is 100%, as the farmer also applies traditional agri-food knowledge received from his father. The Farm is considered as a knowledge hub where several studies in agroecology have been done previously. The farmer is very enthusiastic to learn new knowledge and to transfer his knowledge to new generations. The score for the element Co-creation and Sharing of Knowledge is 100%, as the farmer received training and knowledge on agroecology practices and is willing to transfer and spread the knowledge among other local farmers, students, or researchers. The general score for the element Human and Social Values is 93.75%. It indicates that The Farm maintains fair labor force participation between men and women, provides better working conditions for the labor force and has a succession plan for The Farm. The score for the Circular and Solidarity Economy element is 91.66%, which expresses an advanced level of circularity and solidarity economy for The Farm. The farmer sells all the farm produce in the local market, without any intermediaries. The Farm plays a significant role in feeding the local community through supplying a variety of food items to the local market. The general score of the Responsible Governance element is 100%, which is based on the fact that the farm owner is empowered by owning the land and its natural resources, by having useful knowledge and by being a valued member of the community, involved in local farming organizations (SDG: 12).

Based on the analyzed data, the assigned scores of the 10 elements of agroecology are presented in Figure 2, as a radar diagram. The Farm is strong on efficiency, culture and food tradition, co-creation and sharing of knowledge and responsible governance, with a general score of 100% for each of these four elements. The Farm is less strong on synergies, and circular and solidarity economy (87.5% and 91.66%, respectively), but strong enough on diversity, resilience, and human and social values (93.75% for each). The general score of the recycling element is 62.50%, which is rather low compared to the scores of the other agroecological elements. This lower score is because the biogas plant is currently out of order and there is no plan to reinstall it soon due to the high reinstalling cost. The average score of the 10 elements as indicated by the CAET is 92.29%, which shows an advanced level of transition to agroecology for The Farm.

4. Discussion

4.1. Diversity

The Farm is highly diversified as an integrated crop-livestock system. Due to integration and diversification, high biodiversity is found on the farm. The farmer produces different crops, vegetables and fruit trees, raises livestock, cultivates fish in a small pond, offers lodging facilities for the tourists, and preserves 5% of the farm area for forest trees that provide shelter to wild birds, mammals, amphibians and insects. This mosaic of activities builds a strong ecosystem diversity. Ricciardi et al. (2021) and Sekaran et al. (2021) argue that on an average small-scale crop-livestock integrated farm the yields are higher, especially for the principal crops, and they ensure food security and a greater crop and non-crop biodiversity at the farm scale (SDG:2). The Farm's land use

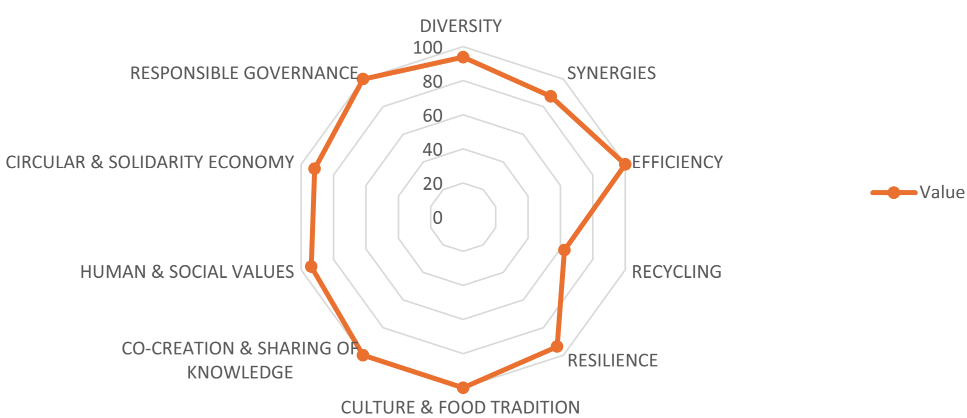

Figure 2. Visualization of the CAET for the farm. Source: Own drawing (2024).

pattern in 2011 is presented in Table 4. It shows that most of the land is used for mixed cropping and mixed orchard, wooded pasture, ranch, and agroforest area.

4.1.1. Diversity of crops, vegetables, and fruits

Around twenty-five types of crops, vegetables and fruits are produced on The Farm. The major crops and vegetables are yucas, taro roots (tiquisque), okra, chili, black pepper, sunflower seeds, vanilla, turmeric, sweet potatoes, corn, and different kinds of legumes. The fruit trees include banana, jackfruit, palm heart, coconut, papaya, red dragon, grapefruit, pineapple, plantain, orange, noni fruit (*morinda citrifolia*), soursop, cocoa fruit, etc. The Farm produces around fifteen varieties of bananas every year, with different colors and tastes. In the vegetable garden, the farmer practices crop rotation and mixed or intercropping. For instance, yucas and taro plants are grown together to maximize soil space. Different kinds of legumes are produced as cover crops to protect the soil and secure nitrogen fixation (SDG:15). The farmer also covers the soil with black plastic to control weed growth. Recently, the farmer introduced a vanilla crop on the farm. Vanilla plants are a type of orchid that climbs on trees. They require about 5 years before they start producing flowers and fruit. The vanilla flower only lives one day, when it needs to be pollinated to produce fruit. Many farmers are using hand pollination of the vanilla flowers to make sure that there will be fruits. After pollination, the vanilla

Table 4. Land use of the farm, 2011.

Use of land	Area (ha)	%
Mixed orchard	0.49	4.94
Palmetto, Musaceae, timber trees	1.64	16.53
Palmetto, Musaceae, coconut, timber trees	0.78	7.86
Peach palm and timber trees	0.19	1.91
Peach palm, short grass, timber trees	0.09	0.91
Plantain, coconut, timber trees	0.05	0.50
Banana, cocoa, timber trees	0.22	2.22
Musaceae and poró trees *(Erythrina poeppigiana).*	0.21	2.12
Musaceae and timber trees	0.22	2.22
Musaceae	0.08	0.81
Vegetable garden	0.39	3.93
Fallow land	0.26	2.62
Paddock (Ranch)	0.80	8.06
Wooded pasture (timber)	1.10	11.09
Forest	0.99	9.98
Production facilities	0.04	0.40
Cabin	0.01	0.10
Drainage network	0.36	3.63
Fish pond	0.31	3.13
Aerial cable	0.21	2.12
Home	0.02	0.20
Ravine	0.36	3.63
San Jose river	1.1	11.02
Total	9.92	100.00

Source: Jiménez and Avellán Zumbado (2012).

plant requires nine months to produce the flavorful vanilla pod, which still needs processing and packaging before being brought to the market.

4.1.2. Diversity of livestock

To get rid of chemical fertilizers, the farmer started producing organic fertilizers on The Farm, using manure from his cows, chickens, ducks, turkeys, a horse and a pig. Currently, seven cows, one pig, one horse, some ducks and thirty chickens supply enough meat, milk, and eggs for household consumption and occasional selling at the market, and enough manure to produce organic fertilizers on The Farm. Forest covers around 5% of the farmland, with about 80% of that area also being used for pasture. The cows, the horse, the pig, and the poultry are free to roam on the farm pasture. They are fed grass, crops, vegetables and fruit waste, as well as green bananas, which are produced organically. The cows have enough space to sleep and rest under a shed. Every year, the family raises one pig for slaughtering at Christmas time for household consumption. There has been no history of an animal accident in the last couple of years on The Farm. Proper treatment can be arranged, however, if any animal gets sick, as veterinary service is available.

4.1.3. Diversity of trees

A huge increase in biodiversity was obtained about 10 years ago when the farmer replanted the forest which had been initially cut to free the land for agriculture. According to the farmer, the agroforest is important for different reasons. Namely, it is a source of sustainable food; it supplies microorganisms (humus), firewood,and ashes; it acts as a shelter and breeding space for wild birds and animals (frogs, e.g. Red-Eyed Tree Frogs), for butterflies, bees, monkeys (e.g. Howler monkey), lizards, leaf cutter ants, foxes/jackals, etc.; it acts as a buffer zone protecting the crops, vegetables and fruit trees from wind and heavy rain; it absorbs carbon dioxide and supplies pesticides for bioecological control (SDG:13). In addition, the forest trees play a significant role in providing shade and in maintaining soil humidity, so important for the living humus of the forest. The fruit trees give support to wildlife habitats through providing shelter and food, and indirectly, these wildlife habitats also play a significant role in increasing yields for crops, vegetables, and fruits through pollination. Different colorful flowers grow on The Farm, including different kinds of orchids, which not only attract butterflies, birds, bees, and other insects, but also constitute a strong attraction for tourists visiting The Farm.

4.1.4. Aquaculture

As a part of integration and diversification of the protein sources, tilapia are farmed in a small pond (4×4 meters). The farmer started farming tilapia around 10 years ago in four ponds. Nowadays, farmed fish is only for family consumption or for selling in the local market. The farmed fish are also one of the main attractions for tourists who visit the farm and like to cook their meals with the fish.

4.1.5. Agri-tourism

The Farm offers visiting and lodging facilities for national and international tourists. University students, researchers, and professors, as well as local people frequently visit the farm for research and recreational purposes. There are three rooms available for renting by the tourists, equipped with cooking and dining facilities. On The Farm, tourists can enjoy the wilderness, can use the trails in the forest to enjoy the natural beauty, to listen to bird songs and observe wildlife, and to generally enjoy the peace of nature. Agri-tourism has diversified and increased The Farm's income and has reduced the financial risk in case of crop, vegetable, fruit, or livestock failure. The Farm confirms recent studies, which show that diversified farms are more stable financially because they create more employment and evade risks generated from crop failure or uncertain markets and policy environments (Garibaldi and Pérez-Méndez 2019).

4.2. Synergies

All the activities on the farm are carefully planned and carried out to build biological synergies and enhance the ecological functions that support farm production and numerous ecosystem services. The seven cows contribute to the physical, chemical, and ecological fertility of the soil, which can improve crop yields, as about 15% of the nitrogen needs of the crops can come from livestock manure (FAO 2024a). In 2012, around 50% of the cow manure was used to produce biogas and the solid residue was used in composting and in producing a liquid solution, which is applied as organic fertilizer directly on the crops. Now, the Farm no longer produces biogas, and the whole amount of cow manure is used for producing organic fertilizer. A large area of the farm (about 25%) is cultivated with palm trees in association with banana trees, coconut trees, and timber trees. The farmer is very proud of his agroforestry solution of associating timber trees with fruit trees. He believes that this diversified tree area allows a better management of shade, provides weed and pest control, prevents the overturning of palm trees, facilitates harvest, and supplies timber for infrastructure building needs on the farm (Jiménez and Avellán Zumbado 2012). Also, the farmer collects microorganisms from the humus which covers the floor of this mixed forest area. The microorganisms are a significant ingredient in the production of organic fertilizers through composting.

A smaller area, of about 2% of the farm, is dedicated to growing various banana trees in association with Poró trees (*Erythrina poeppigiana*), a tall evergreen tree mainly used as a shade and support tree, which is also great at fixing nitrogen in the soil (Jiménez and Avellán Zumbado 2012), and whose foliage can be used as green manure and as a good source of protein fodder for livestock. The San Jose river, which runs through the farm, the fishponds,and the wooded pasture, play a significant role in connecting the agroecosystem and The Farm's landscape. A horse (for work), a turkey and some ducks are kept for decoration and attraction of the tourists. More importantly, the farm contributes to the community wellbeing as it supplies fresh, chemical-free and healthy foods to the local community as well as the nearest cities, by participating weekly in the farmers' market called *Feria Verde* (SDG:3). According to FAO (2016), maximizing synergies between integrated farming systems significantly improves yields per acre, enhances dietary diversity, secures weed and pest control, improves soil structure and fertility and provides a biodiverse habitat. Implementing synergies in the wider food system may cause trade-offs in natural and human systems, but careful attention, responsible governance, involving different actors in cooperation and collaboration can manage the trade-offs (Barrios et al. 2020; Klapwijk et al. 2014).

4.3. Efficiency

4.3.1. Management of soil fertility

Over the years, the farmer has constantly increased the ecological efficiency of the farm (Tamburino and Bravo 2024), by carefully observing the farm's ecology and introducing diverse technological innovations meant to keep the productive systems as natural as possible. These innovations include practicing agroforestry by introducing various tree species, using crop rotation and mixed cropping strategies, allowing the soil to go fallow, and applying only the organic fertilizers and pesticides produced on the farm. It is argued that "Innovative transitions towards enhanced sustainability outcomes should be able to move from input-intensive systems to information and knowledge-based systems of agricultural and food production aiming at further increasing productivity while optimizing the use of external inputs" (Barrios et al. 2020). The Farm produces organic fertilizers from farm waste, with minimum external inputs. These practices reduce the farm's ecological footprint, and increase the soil's regenerative capacity, thus improving the "earth's fullness" (Tamburino and Bravo 2024). The farm also has a large network of about 1,100 meters of drainage canals, built to eliminate excess moisture accumulation during the rainy season. All these innovations have enhanced the soil organic matter and restored the soil microorganisms that make it self-sustainable and more productive.

4.3.2. Productivity, profitability, and household's needs

On an integrated farm, with a diversity of production systems, productivity is measured differently, as even if the productivity of a single crop diminishes, this can be compensated by the higher productivity of another crop, or of the entire diversified system. What really matters on an integrated farm is the energy efficiency of the production system, measured as the amount of energy invested compared to the amount of energy obtained in the crops produced. For instance, to produce one kilocalorie of soybeans, 10 kilocalories of energy need to be invested in modern agriculture in the form of machinery for preparing the soil, sowing the seed and harvesting, as well as using chemical fertilizers and pesticides (Jiménez and Ulate Segura 2023). The same study claims that "And you go to the traditional systems of the Indians, the Tupi or the Guarani, where to produce 10 kilocalories of food in the field, they invest one kilocalorie of energy," "and the adverse environmental effect is minimal" (Jiménez and Ulate Segura 2023).

A 2012 study of The Farm has calculated that all the productive subsystems on the farm were profitable, with the highest profit (38.2%) being recorded by the subsystem cultivated with palm trees in association with banana trees, coconut, and timber trees; the lowest profit (2.5%) was recorded by the livestock subsystem (Jiménez and Avellán Zumbado 2012). These positive results were due to the fact that during the last 15–20 years, The Farm has undergone a transition from conventional farming, in which production was dependent on numerous external resources, leading to substantial economic losses, to agroecological practices. The Farm has "abandoned the activities damaging the environment and has adopted organic practices, with diversified agricultural systems and produce, an ecological management of the crops, soil recovery, increased forested areas, increased economic incomes and a better quality of life" (Jiménez and Avellán Zumbado 2012). The explanation for the lower profit obtained by the livestock system was that, at that time, the livestock (one cow, a bull and three heifers) was in the process of development. In 2024, with seven cows, the livestock system is more ecologically sustainable and financially profitable.

4.3.3. Management of pests, weeds, and diseases

The farmer has made efforts to understand the behavior of the pests and introduced targeted biological pest control measures, by only using organic pesticides produced on the farm. Due to climate change and the warmer weather, pest attacks and the number of weeds has increased significantly. To control the pests and the weeds, the farmer invented his own techniques, which are very effective and environmentally friendly. For instance, he uses bitter leaves from his farm, such as the leaves of Maderonegro (*Gliricidia sepium*) and mixes them with leguminosae (*Fabaceae*) and different types of grasses, along with rainwater and ash (produced on the farm) to make organic pesticides. The farmer sprays this pesticide paste on the crops or on plant leaves with very good results. The ash added in the pesticide is not only for pest control but also good for plant nutrition. The farmer has tested the effect of the homemade organic pesticide and found that it is not only cost effective but also environmentally friendly and non-harmful for human health and the ecosystem. Recently, the farmer faced a big challenge when dealing with a weevil *(picudos)* infestation in his coconut trees. It is a big concern for any coconut tree farmer to protect the coconut palms from beetle attacks. Aggressive chemicals are needed to control the insects, but the farmer did not want to use them. He used pheromones in an effort to control the growth hormones of the beetle, but that technique didn't work. Then, the farmer decided to plant more and more coconut palms to keep a balance between the dying trees and the new trees. Therefore, the technique to fight the coconut infestation by planting more trees to beat the rate of pest reproduction was more ecologically efficient. To control other insect attacks, the farmer also invented a new natural control technique. This technique involved bringing a colony of ants close to the fruit or crop plants, which were attacked by pest insects. The result was that the ants ate all the pests and soon the infestation was gone. A couple of years ago, when the farm owner faced a physical problem with pain in his back which prevented him from bending to weed his field, he invented a new weeding tool which allowed him to weed his fields without bending his body.

4.3.4. Internal and external labour force

The 2012 study has shown that in 2011, The Farm labor force consisted of three family members and one hired hand (Jiménez and Avellán Zumbado 2012), while in 2024 there are four family members and two hired hands working on the farm. The Farm creates employment opportunities not only for the family members but also for the local community, as the farmer's wife, a daughter and a son are working on the farm. In addition to the family members, the farmer hired two permanent workers who work all year round. According to the national law of Costa Rica, the workers received minimum wage, including tax facilities, and health benefits.

4.4. Recycling

The Farm has introduced and maintained circular economy practices during the last 25 years, aiming to reduce the costs of economic activities as well as to purposefully manage the farm waste to produce organic fertilizer, pesticides, and biogas. This interpretation is consistent with findings by FAO (2017a). Every type of organic waste, ranging from crops and vegetable residues, harvest residues, cow and poultry manure, dry leaves, and kitchen waste, have been used to produce either organic fertilizer or biogas or organic pesticides. For several years, this farmer had produced biogas in a biodigester, using half of the cows' manure, and then used the biogas for household cooking. Currently, the biogas plant is shut down due to a technical problem. The remaining half of the cows' manure was mixed with tree leaves, crops, and vegetable waste, microorganisms, kitchen waste, cocoa bean shells, and dried chickpeas to produce organic compost/fertilizer. Crop-livestock systems, which also include agroforestry and aquatic, promote recycling that helps to capture nutrient loss, close nutrient cycles, reduce dependency on external inputs, increase the farm's autonomy and reduce vulnerability and climate shocks for producers. This result is consistent with findings of FAO (2018). The farmer is a genius, as described by his daughter: "He is a chemist, biologist, ecologist, architect, and engineer with an encyclopedic mind, who invented his biodigester, weeding tools, formulas for organic compost and microorganisms for the home-produced fertilizers and pesticides."

4.4.1. Production of organic fertilizer

The high market prices of chemical fertilizers and their long-term negative impacts on the soil, water, human health and the environment convinced the farm owner to stop using these fertilizers. Around 20 years ago, the farmer introduced a complex and innovative anaerobic digester model to produce organic compost by using natural ingredients from the farm. The Farm successfully shifted from using chemical fertilizers to using home-made organic fertilizer produced with very few external inputs, such as calcium and sulfur (Figure 3). The best thing is that nothing is wasted on the farm, which strictly follows circular economy principles. Now, the farmer wants to spread the model around the world, as he believes that the model can contribute to enhancing food security while conserving natural resources (SDG:13).

The process of making organic fertilizer/compost follows two separate steps: (i) making a mountain microorganism solution; and (ii) making compost by adding the solution to farm waste. In the first step, the farmer grows cocoa plants for selling cocoa seeds, cocoa powder as well as artisanal chocolate. The farmer uses cocoa seeds and dried chickpeas for making the organic solution. The cocoa beans have antioxidants that help the fermentation process. The collected cocoa seeds are fermented, then dried and roasted at high temperature. Then, they are crushed into small pieces called cocoa nibs. The farmer also dries and crushes chickpeas into a powder. At the same time, the farmer uses mountain microorganisms, collected from the white layer of the soil from the forest floor (humus), and collected rainwater. Then, the farmer mixes the cocoa nibs/powder, the chickpeas powder, and the mountain microorganisms with molasses/raw sugar, black honey, jelly powder, rainwater, calcium, and sulfur, into an anaerobic digester (a plastic barrel covered with a lid), where the solution is fermented in the absence of oxygen. In this anaerobic environment, bacteria work well and after two weeks, the solution is ready to be used on the compost pile. In the anaerobic digester, the farmer continues to add humus (with microorganisms), rainwater, black honey, and

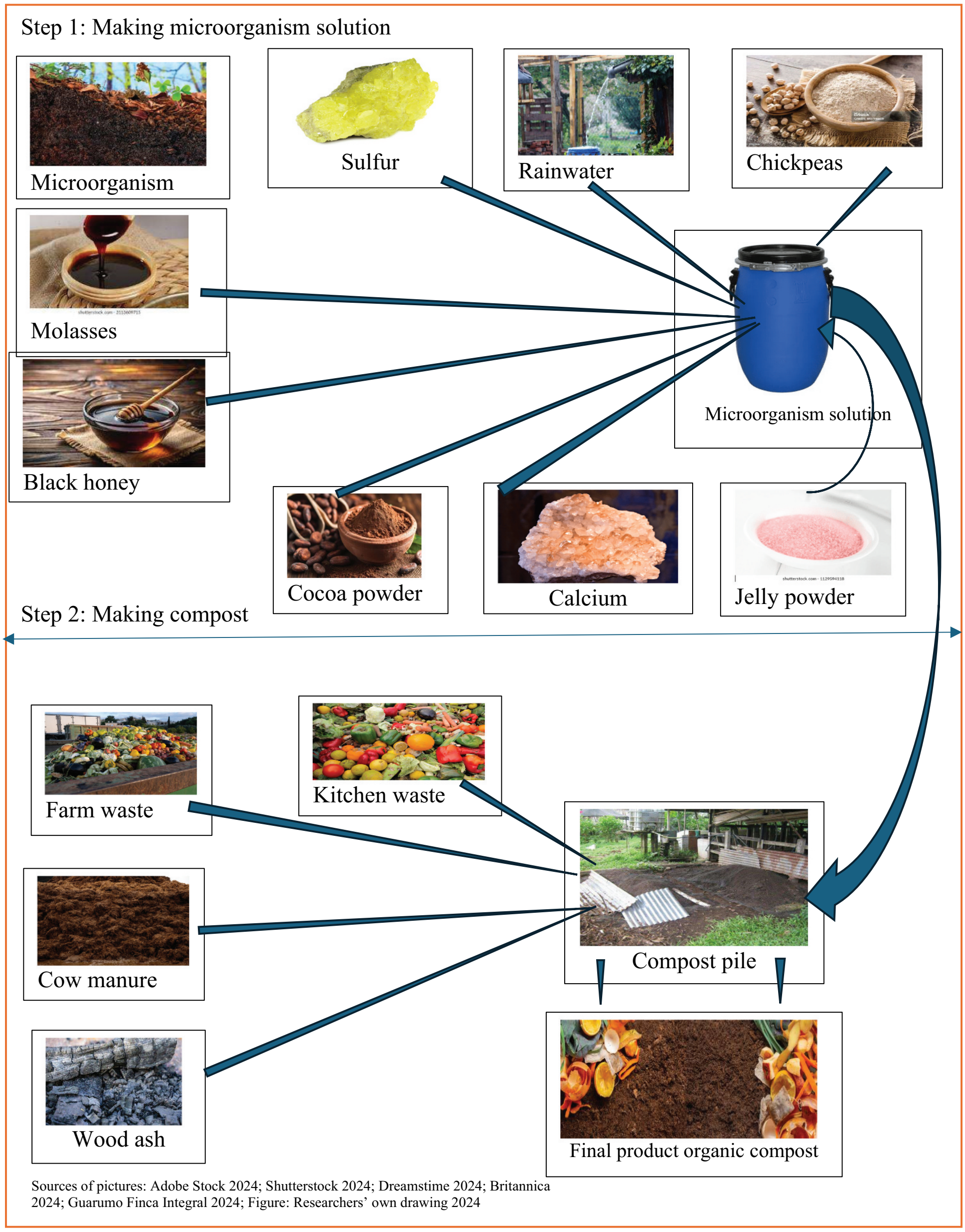

Figure 3. The process of making organic fertilizers from the farm waste. Sources of pictures: Adobe Stock (2024); Shutterstock (2024); Dreamstime (2024); Guarumo Finca Integral (2024); Figure: Researchers' own drawing 2024.

other ingredients to continue the process of making the microorganism solution.

In the second step, the farmer collects crops and vegetable waste, cocoa shells, cow manure with sawdust from the corral, one kind of leaves called *Oharastha* and kitchen waste and piles them in an open space on the farm. The microorganism solution is added to the compost pile, which is then covered with a plastic cover to finish the process of making organic compost or fertilizer. Using the microorganism solution helps control the bad odor coming from the compost pile and also prevents the potential infestation of the compost with fungus and ants. In the compost pile, the farmer also adds California worms to speed up the composting process. Maintaining a controlled temperature in the compost pile is important to protect the worms and beneficial bacteria, since after adding the solution, there is a chance to increase the temperature in the compost pile, which can kill the California worms. The farmer checks the temperature and sometimes opens the plastic cover on the compost pile to reduce the heat and let the compost aerate. This is called a heat-controlled process. The organic compost or fertilizer produced is sufficient to meet the year-round demand of fertilizer on The Farm, and the surplus compost is sold to the neighbors for gardening as well as for fertilizing purposes.

4.4.2. Irrigation and water saving

In Costa Rica, December to April is considered the dry season. But in the last dry season (December 2023 to April 2024), the Farm unexpectedly received large amounts of rain. The Farm managed to get rid of excess water due to the drainage network, which was installed on the farm a long time ago, and which is being maintained constantly. Climate change and water shortages are major challenges for organic farming. On The Farm, there are three old wells, and they are used for watering the fields in the dry season. They use a motor pump for extracting underground water from the wells. The farmer also collects rainwater and uses it for cleaning the cow shed and for making organic compost, as the rainwater has no harmful elements/minerals that may kill the California worms or the microbes. Therefore, the farm depends on an open source of water such as rainwater as well as groundwater from the wells or surface water from the river which crosses the farm without creating any pressure on the farm’s ecosystem.

4.5. Resilience

In ecological systems, resilience has been defined as “persistence of relationships within the system” measured as “the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist” (Holling 1973; Sterk, van de Leemput, and Peeters 2017). Given that farms are complex, linked socio-ecological systems (Ostrom 2009), their resilience depends not only on processes naturally occurring in ecological systems, but also on human management goals and interventions. These must be calibrated to prevent irreversible changes that can lead to the collapse of the ecological systems on which a farm depends. This implies in-depth knowledge of the ecosystems' functions, processes, and the ecological services they provide, and careful design of human interventions, aiming to maintain the complexity and dynamics at work in the agroecological units, before attempting to maximize production levels. This places an increased responsibility on the farmer who must not only know extremely well the eco-bio-chemical and physical structure and potential of the farm, but also needs to design all the farm operations in ways that increase the socio-ecological resilience of the farm. Socio-ecological resilience is "the capacity of agroecosystems to adaptively change in their socio-ecological structure and interactions to withstand and overcome disturbances, stress and change, and to maintain production levels in harmony with the culture, social organization, and satisfaction of the needs and capacity of ecosystems, in an ecologically possible and socially desirable context" (Altieri, Koohafkan, and Holt 2012; Rodríguez et al. 2018).

4.5.1. Stability of production and capacity to recover from perturbations

The owner of The Farm argued that by using only home-made organic fertilizer both the soil productivity and the crop yield increased, while maintaining the soil fertility. To increase and restore the soil nutrients, the farmer used crop rotation and intercropping techniques and left portions of the farmland fallow during a productive cycle (SDG:15). Therefore, The Farm is ecologically resilient through maintaining soil health, as the land has in time acquired that synergy that makes it self-sustainable and more productive. People who visited the farm were astonished to see the production/yield of plantains. The leaves of plantain trees are green and healthy, and the plantain fruits are big. Due to using organic compost only, the soil quality is good, and there is a special synergy among soil nutrients. The farmer is using the same natural home-made compost every year, which plays a significant role in maintaining the farm's microclimate year after year. To control pests and disease attacks, the farmer uses organic pesticides and natural pest control techniques with the potential to enhance both ecological and socio-economic resilience (Perfecto and Vandermeer 2010). In addition to the home-made compost, the farmer uses home-made ashes to reduce soil acidity. To improve the soil's organic carbon, to fix nitrogen, to maintain soil moisture and to reduce soil erosion, the farmer practices minimum till and no-till techniques. He uses a diesel-operated small tiller for tilling the land only when necessary. As a conservation technique, he is trying to follow minimum soil disturbance techniques as well as cover the soil with cover crops like legumes, meniscus and *Arachis pintoi*. Another reason for using cover crops is to get organic certification, as in Costa Rica it is mandatory to grow cover crops for maintaining the soil health. In addition, the planting and harvesting are done manually to reduce the use of fossil fuels, soil compaction as well as to control greenhouse gas emissions (SDG:13).

4.5.2. Mechanisms to reduce vulnerability and indebtedness

The Farm transitioned from conventional farming to agroecological farming around 12 years ago. The transition reduced the farm's vulnerability and the farm's indebtedness. After consolidating an organic and diversified crop-livestock integrated farming system, the farmer's income as well as the capacity of investment have increased (Bellon et al. 2020; Bowles et al. 2020). The long and interconnected drainage system and the buffer zone provided by the forested area protect the farm from floods and cyclones (Altieri et al. 2015). The farmer currently has no debt to any financial institutions, such as banks or credit unions.

4.6. Culture and food traditions

The Farm produces different varieties of organic crops and vegetables, fruits, fish, meat, milk, and eggs. The farmer feeds his family and sells the extra produce in the local farmers' market. The market is a two-hour drive from the farm and the farmer participates in the market every Saturday. He also uses online platforms such as Facebook and Instagram for advertising and selling the farm products. On-farm selling, as well as selling organic produce and food to the tourists visiting the farm, are good alternative options for marketing the produce. The farmer has plans to make and export artisanal chocolate, but the production is small-scale, and the government or the export authority does not provide export facilities or support. As a principle, the farmer believes that first you must feed your family, then the community, then the country, and if there is a surplus, this will be exported. This life philosophy is in line with the agroecological principle of producing locally and feeding the local communities first (Wezel et al. 2020). Normally, the farmer uses the eggs for household consumption and sells the surplus eggs to the local customers and markets. There is a healthy demand for these eggs, as they have different colors, blue, red, and white. The customers like the eggs because they are very tasty, nutritious and healthy, and are laid by local species of chickens. When the chickens are very old and stop laying eggs, the farmer uses them for making a delicious soup for the family. The farmer and the family members process a variety of organic produce on the farm. The Farm is home to 15 varieties of bananas and the farmer preserves the traditional varieties with care (FAO 2017b). The farmer's family dries ripe bananas by using sunlight, preserves dried bananas in glass jars, and sells them in the local market. The family members also use dried bananas for household consumption. They also make unique and good quality chocolate by using home-made and organic ingredients, with no added artificial flavors, colors, or preservatives. To make good quality chocolate (Figure 4), they dry and roast the cocoa seeds harvested from their own farm and break them into cocoa nibs and cocoa powder. Another ingredient, coconut milk, is also produced from the coconuts

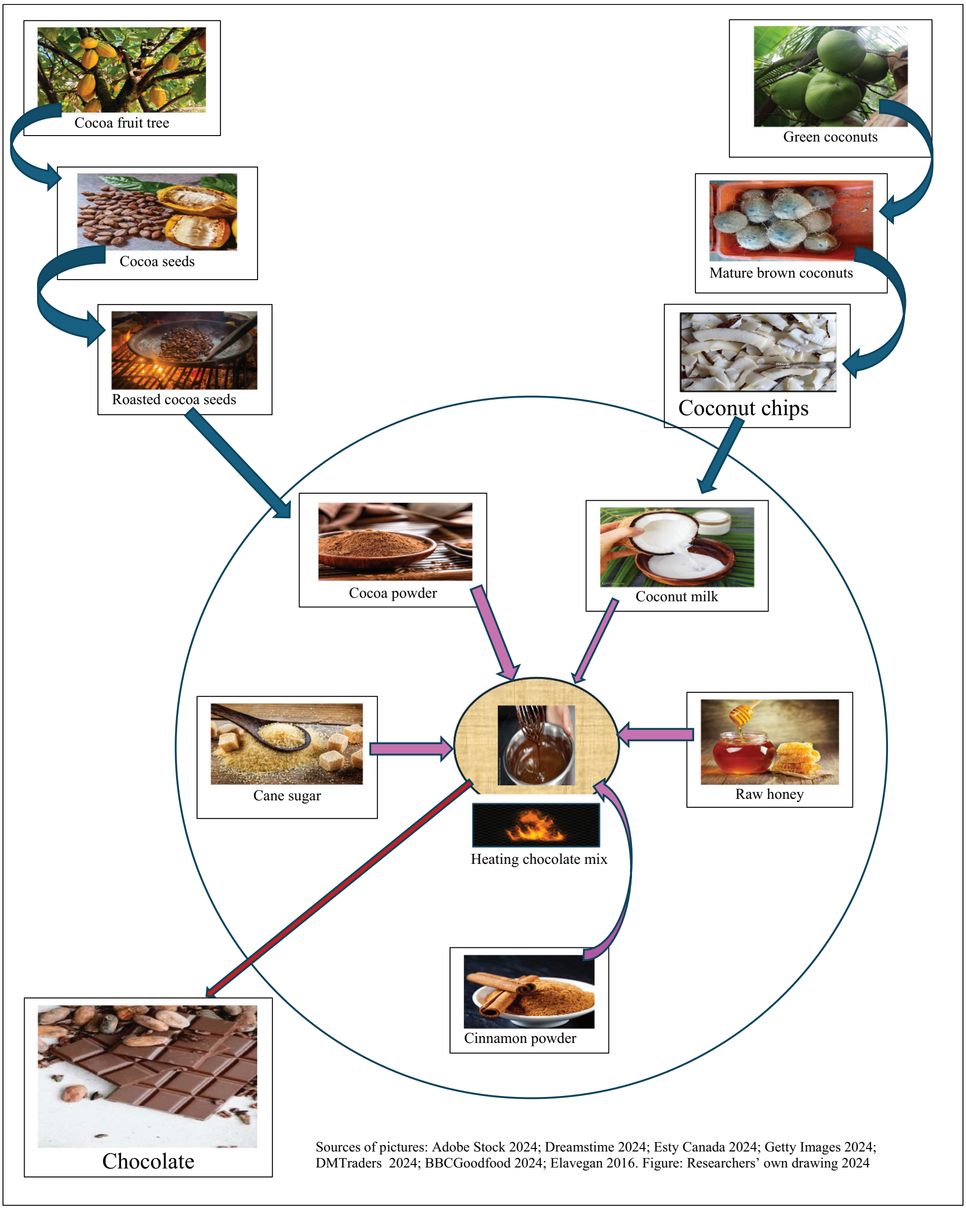

Figure 4. Diagram of how to make homemade organic chocolate. Sources of pictures: Adobe Stock (2024); Dreamstime (2024); Etsy Canada (2024); Gettyimages (2024); DMTraders (2024); BBCGoodfood (2024); Elavegan (2016). Figure: Researchers' own drawing 2024

grown on the farm. Then, they mix cocoa powder, cocoa butter, coconut milk, cane sugar, honey and cinnamon powder, and cook the mixture until a good quality chocolate is obtained. The cocoa nibs and the residual biomass are an important source of nutrients and bioactive compounds, as they contain high dietary fibers, methylxanthines and polyphenols.

The farmer intends to produce cancer medicine from cocoa nibs, as recent research shows that cocoa bean shells can be used as raw material for antioxidants, antivirals, antimicrobials, anti-inflammatory and anti-cancer medicine (Cinar et al. 2021; Sánchez et al. 2023). But the farmer is aware that producing and marketing the medicine from cocoa nibs requires more reliable information, more research and technical and financial support.

4.7. Co-creation and sharing of knowledge

The owner of The Farm gained traditional farming knowledge and learned natural farming techniques from his father. While being a conventional farmer, he always wanted to know more about ecosystem functions and processes and how they can be useful in the operation of the farm, thus allowing him to produce healthier food for his family. Considering the negative impacts of conventional farming on the environment, human health, and climate change, he started the process to transition to organic farming in 2007, after attending a series of workshops organized by the Costa Rican Corporation for Training and Development (CEDECO) (Jiménez and Avellán Zumbado 2012). He became persuaded that he must change his farming practices to conserve the farm's natural resources through environmentally friendly farm management practices that minimize the degradation of the soil and water sources and reduce energy consumption, without compromising the food production and the farm's economic performance. Before starting the transition to agroecology, the farmer gathered more knowledge and prepared himself by taking courses, training stages and workshops on agroecology. In Costa Rica, universities offer free courses and training on tropical studies with the collaboration of the Organization for Tropical Studies (OTS), an organization founded in 1963 (Bendito and Barrios 2016; Nobre et al. 2017). The OTS is a "nonprofit consortium of about fifty universities, colleges and research institutions worldwide with the aims of providing leadership education, research, and the responsible use of natural resources in the tropics" (OTS 2022). The farm owner received the necessary training on organic farming and agroecological practices from a trainer on tropical studies from Brazil.

The CEDECO is a non-governmental and nonprofit organization (founded in 1984) which provides advice, training, and education in agroecology and organic farming to small producers (CEDECO 2024). The organization has its own manual which teaches topics like introductory concepts of organic farming, the processing of biogas from cow manure, controlling insects and diseases, producing manure and microorganism solutions, etc. The most significant strategy of CEDECO is to offer free training and manuals to farmers. The owner of The Farm received free training from this organization whose experts visited The Farm and taught him how to make organic compost and produce the microorganism solution. According to the farmer, the free institutional support available in Costa Rica is very helpful for the farmers who want to transition from conventional farming.

The Farmer has a wealth of agroecological knowledge. He often exchanges this knowledge with his neighbor farmers and aims to transfer this sustainable farming knowledge from generation to generation. The farm has a succession plan, and the farmer is training one of his sons and his daughter, who work part-time on the farm, to continue the agroecological and organic management of the farm. Studying the farmer's innovative work is important because of the potential to spread his hard-earned knowledge to future generations of young farmers, researchers, and policy makers.

4.8. Human and social values

The Farm is home to a family of hard-working people who treat the farm as a living organism with self-sustaining biological mechanisms able to produce not only food but also public goods like ecosystem services and rural vitality. The farm owner and his family are committed to producing local varieties of vegetables and fruits, which have more nutritional value compared to high yielding monocultures or genetically modified varieties. Considering human health, social wellbeing and protection of the environment, the farm owner stopped using chemical fertilizers, pesticides and herbicides and started producing and using only organic fertilizers and pesticides on the farm.

The farmer's family has also opened their farm to the community by building a lodge for visitors, and every year many visitors come to The Farm to observe its practices. The farm owner's wife and their daughter are actively involved in the farm management and decision making. Both are highly educated, the wife is a retired teacher, the daughter is working as a university teacher, which ensures the women's empowerment and gender equity, which is consistent with the findings of FAO (2011). The farm's working environment is good, safe, and embedded in a beautiful, thriving tropical environment (Bezner Kerr et al. 2019). The income of The Farm is enough to cover the family's expenses, including education, recreation and reinvestment, and to pay the wages and health and life insurance for two permanent and other part-time laborers. The farm owner is a very good neighbor, cooperating with the local people, and is a well-respected member of his community.

4.9. Circular and solidarity economy

At the beginning of the transition, the farmer was engaged in different training opportunities to get practical knowledge on agroecology and sustainable farming. As a result, The Farm is organized on strong circular economy principles, recycling and reusing most of the organic waste from the farm and minimizing the external inputs in the production processes. The farmer is active in the local markets (shorter food chain), thus creating and maintaining equitable and sustainable food markets, and strengthening the resilience of the rural fabric that enhances the sustainable income of the producers and fair prices for consumers. This is consistent with the findings of Schipanki et al. (2016), Feliciano (2019) and FAO (2018). The farmer also keeps in touch with university teachers, researchers, and students trying to stay informed about new scientific knowledge on agroecology and organic farming. For organic certification of the farm, the farmer has connections with the Costa Rica government departments and private organizations. The farmer's use of social media and online platforms to market his products help him to buy the necessary inputs, such as California worms, and to sell his produce.

These integrated, self-dependent and sustainable farm management practices are the unique inventions of the farm owner who has tested their validity on The Farm. In April 2024, The Farm family hosted an international group of researchers and students involved in the transdisciplinary sustainability event entitled "The Future of Nature: Sarapiqui" which was organized by the Canadian Memorial University of Newfoundland initiative *For a New Earth* in collaboration with Costa Rica's Universidad Nacional. According to the farmer, around 600 tourists, including students, family, couples, and researchers, are coming to visit the farm every year. This type of research collaboration has wider social and environmental impacts than economic profits.

4.10. Responsible governance

The Farm owner has 10 hectares of land, which gives him full and equitable access to the soil, natural resources, forest, environmental services, and even to the river running through the farm. This access to land and natural resources is a key to social justice (FAO 2018), which empowers the farm owner to participate fully in wealth creation and distribution in his community and society (FAO 2018). The Farm is responsibly managed as "the family takes ownership of the production model, and their women have a greater participation" (Jiménez and Ulate Segura 2023). There is division of labor on the farm, where the farmer's wife makes cheese and is in charge of fish farming, and sometimes takes produce to the market. Moreover, she does some field work, such as shoveling, fruit picking and fertilizing, while the daughter takes care of product development, processing and marketing (Jiménez and Ulate

Segura 2023). The main idea of responsible governance on an integrated, organic farm is mastering the art of intimately knowing the farm's natural ecosystems and letting them work out their functions, processes, and services which, when carefully integrated in the farm's productive activities, "can generate less work and physical effort" (Jiménez and Ulate Segura 2023), and can free the farmer and his family to enjoy the beauty and the bounty of the farm and get involved in other enjoyable or useful activities in the community.

4.10.1. Fairness

The model of integrated farming has a long history in Costa Rica, being practiced in Indigenous traditional farming systems. It was made official in 2005–2007, when the Costa Rican government obtained funding from the Inter-American Development Bank (IDB) for a project aiming to improve sustainable agriculture production systems, including through promotion of integrated farms. That was the time when The Farm started in earnest the process of agroecological transition. But since then the sustainable agriculture "project had no continuity, it was abandoned" (Jiménez and Ulate Segura 2023), though many of the integrated farms created then have continued and are still in existence. But today, "there is no policy that is designed to favor this farm model" (Jiménez and Ulate Segura 2023). The Farm owner faces challenges concerning lack of government financial support and difficulties in getting various certificates for organic production, for registering a trademark or brand, or for obtaining health certificates. He is a member of the Network of Integrated Farms of Costa Rica, a farm association attempting to exert pressure on the government to develop policies and specific actions in support of the integrated farming model. The goodwill of the farmer and his family, his constant efforts for the introduction of innovative techniques, and the application of his hard-earned sustainable farming knowledge make the farm thrive and be an important part of a sustainable community.

4.10.2. Organic certification

The Farm is a certified organic farm, and the farmer needs to renew the certificate every year, which is expensive. The farmer faced difficulties in getting organic certification during the COVID-19 pandemic, as the government stopped issuing organic certificates. Then, the farmer started getting organic certification from the private sector. The Farm now receives organic certification from PrimusLabs Auditing Ops, a professional and personalized service provider in the farm organic certification (USDA 2023). Before organic products enter the market, the Department of Accreditation and Registry in Organic Agriculture under the Ministry of Agriculture and Livestock (MAG) of Costa Rica frequently checks/tests the quality of the products and, if the quality is not adequate, then the farm will lose the organic certificate (Webb 2024).

5. Concluding thoughts

This study shows that the owner of this small-scale organic, integrated family farm did face some challenges in the process of transitioning from conventional farming to agroecological sustainable organic farming but was able to surmount them with intelligent hard work and by carefully observing the natural processes occurring on the farm. According to the theory of sustainability transition (Loorbach et al. 2017), the farmer has taken proper actions by developing a long-term vision (of doing more than optimizing an existing agriculture system to reduce its unsustainability), by reflecting, rethinking, and reshaping his thoughts and actions. He took these actions through continuous learning about agroecological practices and smart and harmonious ways of integrating ecosystem processes, functions, and services in their productive activities, and by continuously experimenting to diversify and adapt his productive systems with the double goal of achieving both ecological and socio-economic efficiency (Loorbach et al. 2017). In other words, the farmer has managed to master both the science and the art of designing and calibrating his economic activities to work with nature and not against it. This effort required essential knowledge of chemistry, biology, soil science, hydrology, economics, and sociology, which the farmer was willing to acquire by joining organized training courses and workshops and by carefully observing both nature and the social context to identify essential needs not only of the family and of the community, but of nature also.

In this long journey, the Farm owner benefited from technical and financial support from specialized NGOs (OTS, CEDECO) and from the Costa Rican government when it was available, such as in 2005–2007 when Costa Rica received financial support from the IDB to strengthen the country's sustainable agriculture productive models. However, in the last decades, the Costa Rican government has failed to capitalize on the sustainability experience and successes of the integrated farming model and has not developed specialized policies to support their continuous existence and evolution. The Farm owner believes that the government should develop special policies for small-scale and organic farmers, providing special incentives for young farmers willing to enter the field of organic and integrated agroecological farming. Among the challenges that the farmer identified are the lack of supportive bank loans or incentives available for small-scale farmers, enabling them to invest in new farm infrastructure, such as solar panels, greenhouses, sustainable farming machinery, or in maintaining old infrastructures, such as the old family biodigester for producing biogas on The Farm. The farmer has access to loans from private banks, but these are expensive due to high interest rates.

Another challenge facing the small-scale organic family farms is the lack of market security in Costa Rica. The government does not have a consistent strategy to promote market security and to provide support for creating new market types, such as for organic food produce or for zero-emissions food products, or to simplify the procedures for food markets or food health certification (Jiménez and Ulate Segura 2023). A proposal for a certificate for small-scale family agriculture, obtained through a certification process that is "simple, cost-efficient and not time consuming," as an instrument for promoting social and territorial cohesion (Stamm 2020), has remained just on paper. A nation-wide policy for developing and protecting sustainable food labels can be a fast and secure way for small-scale, organic family farms to market their wholesome food products, not only in farmers' markets but also in supermarkets, where now about 50% of the food is being sold in Costa Rica (Stamm 2020). A third challenge identified in this study is lack of awareness concerning the existence of this sustainable farming model, not only in Costa Rica but also in other countries. A sustained effort to teach about this alternative farming model at all educational levels, and to disseminate information about the ecological and social advantages of this sustainability model among food consumers and producers worldwide, could contribute to achieving the sustainable production and consumption goals established since 1992 by United Nations and reiterated in 2015 in the Sustainable Development Goals (SDGs) agenda.

This analysis of The Farm's performance demonstrates the importance of producing good and nourishing food on farms, not only for economic profit, but also for a healthier environment and a strong and happy society. According to the farmer, careful integration of activities and processes on small-scale organic farms is agroecologically efficient, as it secures the farm's sustainability measured by its capacity to exist and function as a social-ecological system in the long-term (Ostrom 2009). This study is an example of applied transdisciplinary sustainability research (Lang et al. 2012), as sustainable farming knowledge has been co-created, by integrating academic knowledge with farm practitioners' knowledge, and will be disseminated in the attempt to solve the socially relevant problem of food security and sovereignty. The case study has provided first-hand evidence that the transition to sustainable agroecology organic farming is feasible, when practiced with knowledge, hard work and passion on a small-scale family farm.

This model of sustainable agriculture is able not only to build strong biological relationships in farm activities (through plants-animals, insects-microorganism pesticide, trees-vanilla plant, agro-forestry synergies), but also sustainable relationships between humans (owners-workers on the farm, owners-neighbors, and the larger community at the farmers market, or farmers – visitors through agritourism). The model can build both ecological and socio-economic resilience for human communities, by providing a feasible solution to the double problem of environmental sustainability and food security, which includes also food sovereignty aspects, so important for food-producing farmers. As humans facing this double vital challenge, it is important to remind ourselves of Chesterton's words of wisdom: "We men and women are all in the same boat, upon a stormy sea. We owe to each other a terrible and tragic loyalty" (Chesterton 1987: 290).

This study recommends that governments interested in the wellbeing and social cohesion of their societies should support the dissemination of agroecological practices into farms of any scale, and provide the necessary financial support for their sustainability transition. At the same time, governments should support the existing small-scale diversified agroecological organic family integrated farms model as part of their food security and sovereignty policies. More case studies, as well as comparative studies between conventional and agroecological farming would help bring more evidence and build awareness in the general public worldwide about the benefits of eating fresh, healthy and locally produced food, a guarantee that sustainability in this generation and in future generations is secured.

Acknowledgement

We are grateful to Sean McGrath (Memorial University of Newfoundland) and George Manuel Luna Angulo (National University of Costa Rica) who made possible this research through the Future of Nature Sarapiqui Transdisciplinary Initiative. We also want to thank Adam Beardsworth, Thomas Halford, and Natalie Colleen Penney-Toba (Memorial University of Newfoundland, Grenfell Campus) for their helpful revision of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Declaration

The corresponding author and coauthors have no relevant financial or non-financial competing interests and no potential conflicts of interest. This research did not receive funding from other sources or organizations.

References

Adobe Stock. 2024. Photos. Adobe Stck. Accessed July 19, 2024. https://stock.adobe.com/ca/photos.

Altieri, M. A. 1995. *Agroecology: The science of sustainable agriculture*, 2nd ed. Boulder, CO: Westview Press.

Altieri, M. A., P. Koohafkan, and E. Holt. 2012. Agricultura verde: Fundamentos agroecológicos para diseñar sistemas agrícolas biodiversos, resilientes y productivos

(Green agriculture: Agroecological foundations for designing biodiverse, resilient and productive agricultural systems). *Agroecología* 7 (I):7–18.

Altieri, M., C. I. Nicholls, A. Henao, and M. A. Lana. 2015. Agroecology and the design of climate-resilient farming systems. *Agronomy for Sustainable Development* 35 (3):869–90. doi: 10.1007/s13593-015-0285-2.

Barrios, E., B. Gemmill-Herren, A. Bicksler, E. Siliprandi, R. Brathwaite, S. Moller, C. Batello, and P. Tittonell. 2020. The 10 elements of agroecology: Enabling transitions towards sustainable agriculture and food systems through visual narratives. *Ecosystems & People* 16 (1):230–47. doi: 10.1080/26395916.2020.1808705.

BBCGoodfood. 2024. Top 12 health benefits of cinnamon. Accessed July 19, 2024. https://www.bbcgoodfood.com/howto/guide/health-benefits-cinnamon.

Belfrage, K., J. Björklund, and L. Salomonsson. 2005. The effects of farm size and organic farming on diversity of birds, pollinators, and plants in a Swedish landscape. *AMBIO: A Journal of the Human Environment* 34 (8):582–88. doi: 10.1579/0044-7447-34.8.582.

Bellon, M. R., B. H. Kotu, C. Azzarri, and F. Caracciolo. 2020. To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. *World Development* 125:104682. doi: 10.1016/j.worlddev.2019.104682.

Bendito, A., and E. Barrios. 2016. Convergent agency: Encouraging transdisciplinary approaches for effective climate change adaptation and disaster risk reduction. *International Journal of Disaster Risk Science* 7 (4):430–35. doi: 10.1007/s13753-016-0102-9.

Bezner Kerr, R., C. Hickey, E. Lupafya, and L. Dakishoni. 2019. Repairing rifts or reproducing inequalities? Agroecology, food sovereignty, and gender justice in Malawi. *Journal of Peasant Studies* 46 (7):1499–518. doi: 10.1080/03066150.2018.1547897.

Borras, S. M., M. Edelman, and C. Kay. 2008. Transnational agrarian movements: Origins and politics, campaigns and impact. *Journal of Agrarian Change* 8 (2–3):169–204. doi: 10.1111/j.1471-0366.2008.00167.x.

Bowles, T. M., M. Mooshammer, Y. Socolar, F. Calderon, M. A. Cavigelli, S. W. Culman, W. Deen, C. F. Drury, Y. Garcia, A. Garcia, et al. 2020. Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. *One Earth* 2 (3):284–93. doi: 10.1016/j.oneear.2020.02.007.

Caporali, F. 2007. Agroecology as a science of integration for sustainability in agriculture. *Italian Journal of Agronomy* 2 (2):73–82. doi: 10.4081/ija.2007.71.

Carlile, R., and T. Garnett. 2021. What is agroecology? TABLE explainer series. TABLE, University of Oxford, Swedish University of Agricultural Sciences and Wageningen University & Research.

CEDECO. 2024. Costa Rican corporation for training and development (CEDECO). Accessed June 25, 2024. https://cedeco.or.cr/sobre_nosotros/.

Chesterton, G. K. 1987. The collected works of G. K. Chesterton. In *The illustrated london news, 1908-1910*, ed.L. J. Clipper, and G. J. Marlin, vol. 28, 290. London: Ignatius.

Cinar, Z. Ő., M. Atanassova, T. B. Tumer, G. Caruso, G. Antika, S. Sharma, J. Sharifi-Rad, and R. Pezzani. 2021. Cocoa and cocoa bean shells role in human health: An updated review. *Journal of Food Composition & Analysis* 103:104115. doi: 10.1016/j.jfca.2021.104115.

DMTraders. 2024. Natural raw honey/forest honey/mountain honey. Accessed June 12, 2024. https://www.dmtraders.com/product/natural-raw-honey-forest-wild-honey/.

Dreamstime. 2024. Amazing stock images. Accessed July 19, 2024. https://www.dreamstime.com/stock-photos.

Elavegan. 2016. Homemade coconut milk recipe/dairy free. https://elavegan.com/homemade-coconut-milk-recipe/.

Etsy Canada. 2024. Cocoa seeds. Accessed July 19, 2024. https://images.app.goo.gl/y3bLuf4QkCAKHBbV8.

FAO. 2011. *The state of food and agriculture. Women in agriculture: Closing the gender gap for development*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i2050e.pdf(openinanewwindow).

FAO. 2016. Scaling-up integrated rice-fish systems – Tapping ancient Chinese know-how. South-South cooperation, Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/62a24056-6f82-44af-b2a2-4c8e9994af23/content.

FAO. 2017a. *Sustainable agriculture for biodiversity – biodiversity for sustainable agriculture*. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2017b. *The future of food and agriculture – trends and challenges*. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2018. The 10 elements of agroecology: Guiding the transition to sustainable food and agriculture systems. Food and Agriculture Organization of the United Nations.

FAO. 2019. *TAPE: Tool for agroecological performance evaluation - Process of development and guidelines for application. Test version*. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2024a. Agroecology knowledge hub. Tool for agroecological performance evaluation (TAPE). Food and agricultural organization of the United Nations (FAO). Accessed July 15, 2024. https://www.fao.org/agroecology/overview/en/.

FAO. 2024b. Scaling up climate ambition on land use and agriculture through nationally determined contributions and national adaptations plans (SCALA). Food and Agricultural Organization of the United Nations (FAO). Accessed July 15, 2024. https://www.fao.org/in-action/scala/countries/costa-rica.

Feliciano, D. 2019. A review on the contribution of crop diversification to goal 1 "no poverty" in different world regions. Sustainable DevelopmentSustainable Development 27:795–808.

Francis, C., G. Lieblein, S. R. Gliessman, T. A. Breland, N. Creamer, R. Harwood, L. Salomonsson, J. Helenius, D. Rickerl, R. Salvador, et al. 2003. Agroecology: The ecology of food systems. *Journal of Sustainable Agriculture* 22 (3):99–118. doi: 10.1300/J064v22n03_10.

Galli, F., A. Cavicchi, and G. Brunori. 2019. Food waste reduction and food poverty alleviation: A system dynamics conceptual model. *Agriculture and Human Values* 36 (2):289–300. doi: 10.1007/s10460-019-09919-0.

Galt, R. E., N. Pinzon, N. I. Robinson, and M. B. B. Coronil. 2024. Agroecology and the social sciences: A half-century systematic review. *Agricultural Systems* 216:103881. doi: 10.1016/j.agsy.2024.103881.

Garibaldi, L. A., and N. Pérez-Méndez. 2019. Positive outcomes between crop diversity and agricultural employment worldwide. *Ecological Economics* 164:106358. doi: 10.1016/j.ecolecon.2019.106358.

Gettyimages. 2024. Cane sugar. Accessed July 19, 2024. https://www.gettyimages.ca/search/2/image-film?phrase=cane+sugar.

Giller, K. E., T. Delaune, J. V. Silva, K. Descheemaeker, G. van de Ven, A. G. T. Schut, M. van Wijk, J. Hammond, Z. Hochman, G. Taulya, et al. 2021. The future of farming: Who will produce our food? *Food Security* 13 (5):1073–99. doi: 10.1007/s12571-021-01184-6.

Gliessman, S. 2016. Transforming food systems with agroecology. *Agroecology & Sustainable Food Systems* 40 (3):187–89. doi: 10.1080/21683565.2015.1130765.

Gliessman, S. 2018. Defining agroecology. *Agroecology & Sustainable Food Systems* 42 (6):599–600. doi: 10.1080/21683565.2018.1432329.

Gliessman, S., H. Friedmann, and P. H. Howard. 2019. Agroecology and food sovereignty. *Institute of Development Studies (IDS) Bulletin* 50 (2). https://bulletin.ids.ac.uk/index.php/idsbo/article/view/3038/Online%20article.

Gliessman, S. R. 1990. *Agroecology: Researching the ecological basis for sustainable agriculture*. New York: Springer.

Guarumo Finca Integral. 2024. Facebook page, Finca Integral El Guarumo. Accessed July 10, 2024. https://www.facebook.com/p/Finca-Integral-El-Guarumo-100065667572491/.

Hazell, P. 2015. Is small farm led development still a relevant strategy for Africa and Asia? In *The fight against hunger and malnutrition. The role of food, agriculture and targeted policies*, ed. D. E. Sahn, 192–207. Oxford: Oxford Scholarship Online.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4 (1):1–23. doi: 10.1146/annurev.es.04.110173.000245.

IUCN. 2020. Approaches to sustainable agriculture. Exploring the pathways towards the future of farming. International Union for Conservation of Nature (IUCN). Ministry of Agriculture, Nature and Food Quality of the Netherlands.

Jiménez, W. 2001. Los sistemas diversificados de producción en la economía campesina de la región Nor-Atlántica de Costa Rica (Diversified production systems on small-scale farms in the North Atlantic Region of Costa Rica). *Perspectivas Rurales* 5:201–23.

Jiménez, W. 2021. Reactivación de la economía rural costarricense y de la pequeña producción agropecuaria: ?Utopía o mito (Reactivation of the Costa Rican rural economy and small production agriculture: Utopia or mit? *Ambientico* 277 (1): 4–14.

Jiménez, W., and M. J. Avellán Zumbado. 2012. *Estudio de caso: Finca integral El Guarumo Familia Murillo Vega en Sarapiquí-Heredia*. Universidad Nacional, Heredia, Costa Rica.

Jiménez, W., and M. Ulate Segura. 2023. Entrevista “La experiencia de las fincas integrales y su contribución para la seguridad y soberanía alimentaria en Costa Rica” (The experience of integrated farms and their contribution to food security and sovereignty in Costa Rica). *Perspectivas Rurales Nueva Época* 21 (41):1–34. doi: 10.15359/prne.21-41.3.

Jordan, S. 2022. A brief history of Costa Rica’s national parks system. *The Tico Times*. Accessed July 19, 2024.

Keleman, A., J. Hellin, and D. Flores. 2013. Diverse varieties and diverse markets: Scale-related maize ‘profitability crossover’ in the central Mexican highlands. *Human Ecology* 41:683–705.

Klapwijk, C. J., M. T. van Wijk, T. S. Rosenstock, P. J. A. van Asten, P. K. Thornton, and K. E. Giller. 2014. Analysis of trade-offs in agricultural systems: Current status and way forward. *Current Opinion in Environmental Sustainability* 6:110–15. doi: 10.1016/j.cosust.2013.11.012.

Laforge, J. M. L., B. Dale, C. Z. Levkoe, and F. Ahmed. 2021. The future of agroecology in Canada: Embracing the politics of food sovereignty. *Journal of Rural Studies* 81:194–202. doi: 10.1016/j.jrurstud.2020.10.025.

Lang, D. J., A. Wiek, M. Bergmann, M. Stauffacher, P. Martens, P. Moll, M. Swilling, and C. J. Thomas. 2012. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science* 7 (1):25–43. doi: 10.1007/s11625-011-0149-x.

Liebert, J., R. Benner, R. B. Kerr, T. Björkman, K. T. De Master, S. Gennet, M. I. Gómez, A. K. Hart, C. Kremen, A. G. Power, et al. 2022. Farm size affects the use of agroecological practices on organic farms in the United States. *Nature Plants* 8 (8):897–905. doi: 10.1038/s41477-022-01191-1.

Loorbach, D., N. Frantzeskaki, and F. Avelino. 2017. Sustainability transitions research: Transforming science and practice for societal change. *Annual Review of Environment and Resources* 42:599–626.

Lovell, S. T., V. E. Mendez, D. L. Erickson, C. Nathan, and S. DeSantis. 2010. Extent, pattern, and multifunctionality of treed habitats on farms in Vermont, USA. *Agroforestry Systems* 80:153–71.

Lowder, S. K., M. V. Sánchez, and R. Bertini. 2021. Which farms feed the world and has farmland become more connected? *World Development* 142:105455. doi: 10.1016/j.worlddev.2021.105455.

LVC. 2010. *Sustainable peasant and family farm agriculture can feed the world*. Jakarta, Indonesia: La Vía Campesina (LVC).

Muhie, S. H. 2022. Novel approaches and practices to sustainable agriculture. *Journal of Agriculture and Food Research* 10:100446. doi: 10.1016/j.jafr.2022.100446.

Nobre, M., K. Hora, C. Brito, and S. Parada. 2017. *Atlas de las mujeres rurales de América Latina y el Caribe – al tiempo de la vida y de los hechos(Atlas of Rural Women in Latin America and the Caribbean)*. Santiago de Chile: FAO-RLC.

Nyéléni.2007. Declaration of the forum for food sovereignty, Nyéléni, Mali. Available at Accessed June 27, 2024. https://nyeleni.org/IMG/pdf/DeclNyeleni-en.pdf .

Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325 (5939):419–22. doi: 10.1126/science.1172133.

OTS. 2022. Annual report 2022. Organization for Tropical Studies (OTS). https://tropicalstudies.org/wp-content/uploads/2019/04/Annual-Report-2022.pdf.

Pekin, B. K. 2016. Anthropogenic and topographic correlates of natural vegetation cover within agricultural landscape mosaics in Turkey. *Land Use Policy* 54:313–20. doi: 10.1016/j.landusepol.2016.02.029.

Perfecto, I., and J. Vandermeer. 2010. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proceedings of the National Academy of Sciences* 107 (13):5786–91. doi: 10.1073/pnas.0905455107.

Pimbert, M. P., N. I. Moeller, J. Singh, and C. R. Anderson. 2021a. Agroecology. *Agroecology and Livelihoods Collaborative, University of Vermont* 1–42. doi: 10.1093/acrefore/9780190854584.013.298.

Pimbert, M. P., N. I. Moeller, J. Singh, and C. R. Anderson. 2021b. Agroecology. *Oxford Research Encyclopedia of Anthropology*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190854584.013.298.

Pretty, J. N., J. E. Bragg, and R. E. Hine. 2002. Reducing food poverty by increasing agricultural sustainability. *Agriculture, Ecosystems & Environment* 95 (1):217–34. doi: 10.1016/S0167-8809(02)00087-7.

Ricciardi, V., Z. Mehrabi, H. Wittman, D. James, and N. Ramankutty. 2021. Higher yields and more biodiversity on smaller farms. *Nature Sustainability* 4 (7):651–57. doi: 10.1038/s41893-021-00699-2.

Rodríguez, L. C., J. A. C. González, A. R. Kapuscinski, K. Locke, and M. Fernandez. 2018. How to make prosperous and sustainable family farming in Cuba a reality. A. R. Kapuscinki, K. Locke, and Fernandez, M. eds. *Elementa: Science of the Anthropocene* 6 (77). doi: 10.1525/elementa.324.

Rosado-May, F. J. 2015. The intercultural origin of agroecology: Contributions from Mexico. In *Agroecology: A transdisciplinary, participatory and action-oriented approach*, ed. V. E. Méndez, B. Christopher, C. Roseann, and S. R. Gliessman, 123–38. Boca Raton, FL: CRC Press.

Rosset, P. 2013. Re-thinking agrarian reform, land and territory in La via Campesina. *Journal of Peasant Studies* 40 (4):721–75. doi: 10.1080/03066150.2013.826654.

Rosset, P. M., and M. E. Martínez-Torres. 2012. Rural social movements and agroecology: Context, theory, and process. *Ecology and Society* 17 (3). doi: 10.5751/ES-05000-170317.

Sabau, G. L. 2024. *Critical realism and the objective value of sustainability. Philosophical and ethical approaches*. London and, New York: Routledge.

Sánchez, M., A. Laca, A. Laca, and M. Díaz. 2023. Cocoa been shell: A by-product with high potential for nutritional and biotechnological applications (Edt.: N. Jiménez-Moreno,

I. E. Catalán, and C. Ancin-Azpilicueta). *National Library of Medicine* 12 (5):1028. doi: 10.3390/antiox12051028.

Schipanski, M. E., G. K. Macdonald, S. Rosenzweig, M. Jahi Chappell, E. M. Bennett, R. Bezner Kerr, J. Blesh, T. Crews, L. Drinkwater, J. G. Lundgren, et al. 2016. Realizing resilient food systems. *BioScience* 66 (7):600–10.

Sekaran, U., L. Lai, D. A. N. Ussiri, S. Kumar, and S. Clay. 2021. Role of integrated crop-livestock systems in improving agriculture production and addressing food security – a review. *Journal of Agriculture and Food Research* 5:100190. doi: 10.1016/j.jafr.2021.100190.

Shutterstock. 2024. All images. Shutterstock. Accessed July 19, 2024. https://www.shutterstock.com/search/agro-ecology.

Singh, G., A. Singh, P. Wagh, P. Sasane, A. Tutlani, and R. Kumar. 2024. Agro-ecology: Integrating ecology into agricultural systems. In *Fields of Tomorrow*: *Advancements in Modern agriculture*, ed.B. Prasad, D. Kumar, S. Chouhan, A. Tutlani, S. Kumari and R. Kumar, 1–24. Bilaspur, Chhatisgarh, India: Astitva Prakashan.

Stamm, A. 2020. *Inclusive and sustainable agriculture in Costa Rica. A quality label to promote solidarity-based trade*. San José: Friedrich-Ebert-Stiftung (FES) Costa Rica.

Sterk, M., I. A. van de Leemput, and E. T. H. M. Peeters. 2017. How to conceptualize and operationalize resilience in socio-ecological systems. *Current Opinion in Environmental Sustainability* 28:108–13. doi: 10.1016/j.cosust.2017.09.003.

Tamburino, L., and G. Bravo. 2024. Ecological efficiency: The ability to achieve human well-being while limiting environmental impact. *Environmental and Sustainability Indicators* 21:100322. doi: 10.1016/j.indic.2023.100322.

USDA. 2023. National organic program: Audit and corrective action report. United States Department of Agriculture.

Varghese, S. 2022. *What is agroecology, and how can it provide solutions to crises that plague our food systems and create food democracies*. Minneapolis, Minnesota, USA: Institute for Agriculture & Trade Policy.

Webb, A. Q. 2024. *Organic farming, I the land of agrochemicals*. EL PAIS. https://english.elpais.com/economy-and-business/2024-02-17/organic-farming-in-the-land-of-agrochemicals.html.

Wezel, A., S. Bellon, T. Doré, C. Francis, D. Vallod, and C. David. 2009. Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development* 29 (4):503–15. doi: 10.1051/agro/2009004.

Wezel, A., B. G. Herren, R. B. Kerr, E. Barrios, A. L. R. Goncalves, and F. Sinclair. 2020. Agroecology principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development* 40 (6). doi: 10.1007/s13593-020-00646-z.

Woodhill, J., S. Hasnain, and A. Griffith. 2020. *Farmers and food systems: What future for small-scale agriculture?* Oxford: Environmental Change Institute, University of Oxford.