

Descriptive Study of the Theoretical and Conceptual Framework of the Intercropped Milpa System with Fruit Trees in Veracruz

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ABSTRACT

Introduction: The Intercropped Milpa System with Fruit Trees (MIAF) constitutes an agroforestry strategy that integrates maize, beans, or other legumes with fruit species, creating a more resilient and sustainable agroecosystem.

Objective: This study aims to analyze, from a soil fertility perspective, the theoretical and conceptual contributions of the MIAF system in the Los Tuxtlas region of Veracruz, in order to support its relevance to agricultural productivity and the improvement of farmers' quality of life.

Methodology: A state-of-the-art analysis was conducted on agroecosystems and the MIAF system through a comprehensive review of the Scopus database. Disciplines, activities, and theories directly related to this system were examined, emphasizing its role in agricultural sustainability.

Results: A total of 13,142 documents related to the term "Agroecosystem" were identified over the past 15 years, spanning 10 countries, four document types, and 11 thematic areas. Regarding "MIAF," 33 scientific articles published between 2015 and 2025 across 10 countries were found. Twelve disciplines and their respective activities were characterized, and five theories closely linked to the system were identified, forming a robust conceptual framework to understand its functioning and potential. Conclusion: MIAF emerges as an innovative alternative to conventional agricultural systems. Its capacity to generate ecological, economic, and social benefits combined with its comprehensive approach positions it as a strategic option for food security, rural development, and environmental conservation.

Keywords: Theory, MIAF, terraces, hillsides.

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INTRODUCTION

The term Agroecosystem (AES) originates from the combination of Agro (land as a source of production) and Ecosystem. Agriculture derives from the Latin ager (field) and culture (to cultivate), and is defined as the activity through which human beings manage

natural resources, energy, and information to produce and reproduce plants and animals for anthropocentric purposes (FAO, 2001). The concept began to be used with the creation of the journal *Agro-Ecosystem* (Harper, 1974) and subsequently, in Mexico, with the first seminar on Agroecosystems (Hernández X., 1977).

Currently, the agroecosystem is conceived as a conceptual construction that refers to physical spaces modified by humans to generate social satisfiers, both material and immaterial, and, like ecosystems, includes biotic and abiotic components and their interactions (Pérez-Vázquez, 1996). For Hernández X. (1977), it is a transformed ecosystem for the use of resources in agriculture, livestock, forestry, and wildlife. Odum (1984) defined it as a domesticated ecosystem, situated between natural and artificial ones. Conway (1987) described it as an ecological system altered to produce fibers or food, while Marten (1988) defined it as a complex of air, water, soil, plants, animals, and microorganisms in an area modified for agricultural purposes.

The evolution of the concept has not been linear, as it has integrated diverse approaches and disciplines; for example, early agronomic approaches (19th-20th centuries), focused on efficiency and yield (Liebig, 1843; King, 1911); agricultural ecology (mid-20th century), which recognized ecological complexity in agriculture (Odum, 1953; Watt, 1968); agroecology (from the 1970s to the present), consolidated as a holistic and social discipline integrating ecology, economy, and society (Altieri, 1987; Gliessman, 2007); and agroecology for food sovereignty and social justice, with an emphasis on fair and equitable food systems (Holt-Giménez *et al.*, 2013; IPES-Food, 2016). These transformations involve significant methodological challenges, as well as the need for holistic, multidisciplinary, participatory, long-term, adaptive approaches based on agroecology. According to Gliessman (2007), IFOAM (2008), and FAO (2018), holistic, participatory, and systems approaches stand out, along with qualitative and quantitative research methods oriented toward sustainability. On the other hand, the Los Tuxtlas region, Veracruz, is characterized by high biodiversity, abundant natural resources, and complex terrain with steep slopes. However, the expansion of the agricultural frontier and traditional tillage practices have led to soil degradation, water erosion, and decreased fertility, compromising agricultural productivity and the socioeconomic stability of small producers. In this context, since the late 1980s, technologies adapted to local conditions have been developed with the aim of improving agroecosystem sustainability. One of the first innovations was the implementation of Live Wall Terraces (TMV) in 1988, using *Gliricidia sepium* (Jacq.) hedgerows reinforced with runoff filters. This technology allowed for the delimitation of cultivable strips and the gradual formation of terraces, reducing erosion and improving water and nutrient retention. In a period of eight years, TMV reduced soil losses from 146 t ha⁻¹ yr⁻¹ under traditional tillage to only 2 t ha⁻¹ yr⁻¹. Likewise, after five years of observation, the runoff coefficient decreased from 30% to 15%; sediment analyses also revealed a higher concentration of organic matter and nutrients in TMV, although total losses were lower than in the conventional system. The loss of exchangeable bases (K, Ca, and Mg) was also significantly lower in TMV, evidencing its effectiveness in conserving soil fertility. In terms of productivity, the average annual maize yields reached 4.95 t ha⁻¹ in live wall terraces, compared to 4.12 t ha⁻¹ in traditional tillage. Furthermore, the stability of production was higher in TMV. However,

continuous planting over 13 maize cycles showed a slight decrease in fertility, reflected in soil acidification (0.43 pH units), reduction in organic matter (0.56%), and losses of potassium and calcium in the donor section of the terrace. These results showed that, although TMV is effective in mitigating erosion and improving yield stability, it does not fully resolve the challenges of agricultural sustainability. In response to this situation, INIFAP and the Colegio de Postgraduados developed in 2003 the Intercropped Milpa System with Fruit Trees (MIAF) as a technological evolution of TMV. This multi-objective system seeks to rescue the central principles of the traditional milpa, incorporating modern agronomic knowledge. MIAF integrates a fruit tree (overstory), maize (mesocrop), and a legume such as bean (understory), enabling intense crop interaction over time and space, optimizing the use of natural resources. The reported benefits of MIAF encompass biological, technical, and socioeconomic dimensions: increased net income and family employment, water erosion control, improved soil fertility, higher productivity, microclimate regulation, promotion of biodiversity, carbon sequestration, and long-term sustainability (Nájera *et al.*, 2018). In this regard, MIAF is conceived not only as an agricultural technology, but as a comprehensive rural development strategy capable of simultaneously addressing the environmental and socioeconomic problems of small producers in Los Tuxtlas. The need for this study lies in the fact that the Los Tuxtlas region is currently under significant agricultural and environmental pressure, resulting in fertility loss, erosion, and low yield stability. These conditions directly affect producers' quality of life and threaten regional food security. Analyzing the MIAF system from a soil fertility perspective will scientifically support its relevance as a viable alternative to traditional systems, providing a conceptual and practical framework to guide public policies, conservation strategies, and agricultural extension programs. The hypothesis is that the implementation of the MIAF system in the Los Tuxtlas region improves soil fertility and agricultural productivity, while strengthening the socioeconomic resilience of small producers in contrast to conventional systems. Based on this, the aim of the research was to analyze, from the perspective of soil fertility, the theoretical and conceptual contributions of the MIAF system in the Los Tuxtlas region, Veracruz, in order to support its relevance in agricultural productivity and in the improvement of the producers' quality of life.

MATERIALS AND METHODS

Stage I. Information Search and Analysis

In the first stage, a state-of-the-art analysis of the concept of Agroecosystem and the Intercropped Milpa System with Fruit Trees (MIAF) was carried out through scientific articles indexed in the Scopus platform, considering keywords, titles, and abstracts. Based on this information, corresponding metrics were generated for the aforementioned terms, as well as bibliometric maps of these concepts using the VOSviewer software. Additionally, a description was made of the main disciplines and activities that, from the perspective of the authors of this document, should be considered when studying the MIAF system in Mexico, as well as a description of the main theories inherent to the study of the multi-objective MIAF system. The bibliometric and scientific mapping study of the literature on MIAF and related concepts was conducted following PRISMA criteria for record

selection/filtering and classical guidelines for “science mapping” (Page *et al.*, 2021; Aria & Cuccurullo, 2017; van Eck & Waltman, 2010). Regarding eligibility criteria, inclusion and exclusion concepts were applied. For inclusion, peer-reviewed articles and reviews, proceedings and chapters with scientific committees, and key institutional technical manuals providing theory, methods, or empirical evidence on MIAF/TMV, soil fertility/erosion, productivity, and socioeconomic aspects were considered. For exclusion, non-peer-reviewed outreach notes, documents lacking complete metadata, duplicates, and out-of-scope works were discarded.

Screening and Extraction Process

Screening was carried out in two phases (title-abstract and full text) by two reviewers, with discrepancies resolved by consensus. A PRISMA 2020 diagram is reported, and Cohen’s kappa was calculated for inter-rater agreement (Page *et al.*, 2021). For data extraction, the following were considered: year, document type, country/affiliation, funding, journal, keywords (author/indexed), citations, cited references, methods, soil variables (pH, OM, N, P, K, Ca, Mg), productivity/yield metrics, and erosion/runoff indicators when available.

Bibliometric Indicators

Three indicators were considered. The first was production and impact, which included the annual number of publications, total/average citations, and field index. The second was core sources, focusing on the identification of “core” journals through Bradford’s law and dispersion zones (Bradford, 1934; Vickery, 1948; contemporary analyses and cautions). The third indicator was collaboration structure, which examined co-authorship networks (authors, institutions, countries) and cluster density.

Scientific Mapping and Topics

This activity included the co-occurrence of keywords (author/indexed) and co-citation of references to identify research schools and fronts (Callon *et al.*, 1991; Cobo *et al.*, 2011). Core, emerging, and declining topics were analyzed (temporal evolution through moving windows). The expected thematic axes considered were: (i) soil conservation/erosion–runoff; (ii) fertility and Cation Exchange Capacity (CEC); (iii) topological design and densities (overstory/mesocrop/understory); (iv) productivity and income; and (v) socio-environmental dimensions and gender. Following the mapping, an in-depth reading was conducted of clusters related to Los Tuxtlas/TMV (erosion control, fertility, productivity) to contextualize why the region demands this study: steep slopes, historical erosion, and the TMV MIAF technological trajectory with evidence of reduced soil loss/runoff and improved yields.

On another note, regarding the maps generated with VOSviewer, it is necessary to mention that this is a free, Java-based software program designed to construct, visualize, and explore bibliometric networks. It was created to clearly and precisely represent complex maps of scientific literature using advanced features such as zooming, panning, and intelligent labeling, particularly useful when handling hundreds or thousands of elements. Furthermore, this software uses a technique known as VOS mapping (Visualization of

Similarities), in which the distance between two elements reflects the strength of their relationship: the closer they are, the stronger the relationship (e.g., co-authorship, co-occurrence, citations).

Stage II. Interpretation of Results

Based on the generated information, a theoretical descriptive analysis was conducted on the main theories developed under a systemic approach within the Intercropped Milpa Agroecosystem with Fruit Trees (MIAF).

RESULTS AND DISCUSSION

State-of-the-Art Metrics on Agroecosystems and the MIAF System

When conducting a joint bibliographic search using the terms Agroecosystem and Intercropped Milpa System with Fruit Trees (MIAF), only two scientific articles were found, published in 2021 and 2023. However, when analyzing the terms separately, significant differences were identified in the coverage of the literature. For the term Agroecosystem, a total of 13,142 documents published over the last 10 years (2015-2025) were retrieved, spanning 10 countries, four main document types, and 11 distinct thematic areas (Figure 1). In this context, the high volume of scientific production reflects a growing global interest

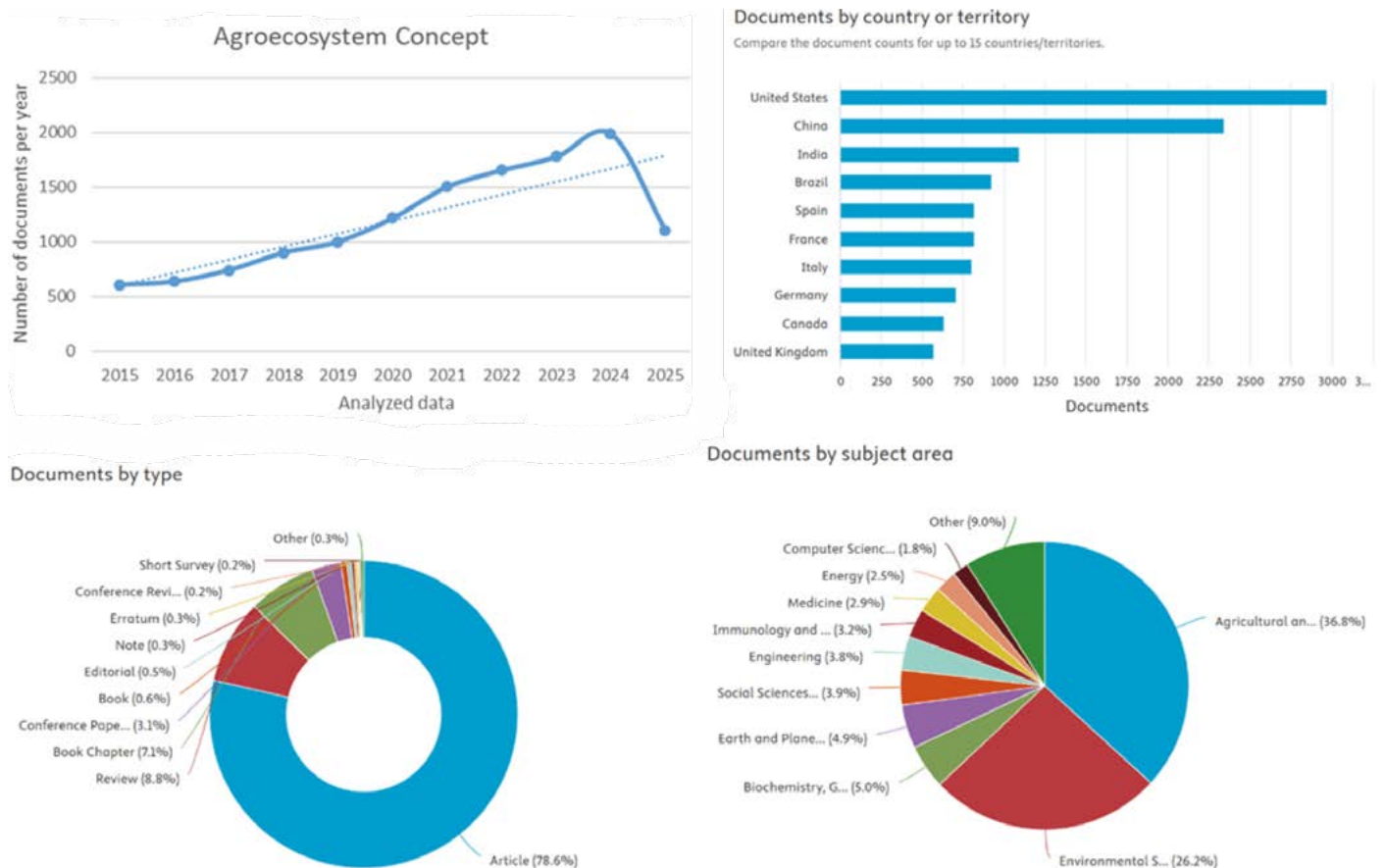


Figure 1. Metrics found on the Scopus platform with the word Agroecosystem.

in agroecosystems, driven by contemporary challenges such as food security, resilience to climate change, and the need for sustainable agricultural systems (Altieri & Nicholls, 2020). The predominance of the United States and China in scientific output aligns with their leadership in agricultural and technological research, as well as with their access to infrastructure, funding, and supportive policies for innovation in the agricultural sector (FAO, 2022).

On the other hand, the concentration of studies within the fields of Agricultural Sciences and Environmental Sciences is consistent with the traditional techno-ecological focus of agroecosystem research. However, a noticeable underrepresentation of disciplines such as Economics, Sociology, and Political Science is observed fields that are essential for addressing the socioeconomic, cultural, and governance dimensions necessary to achieve the comprehensive sustainability of these systems (Gliessman, 2018). This pattern suggests that, although ecological and technical knowledge is well documented, significant gaps remain in understanding the human and social dimensions of agroecosystems. These gaps hinder the development of management strategies that are both effectively sustainable and globally equitable.

Regarding the second keyword, Intercropped Milpa System with Fruit Trees (MIAF), a total of 33 documents published between 2015 and 2025 were identified (Figure 2). It was observed that, since the year 2000, there has been a significant increase in research

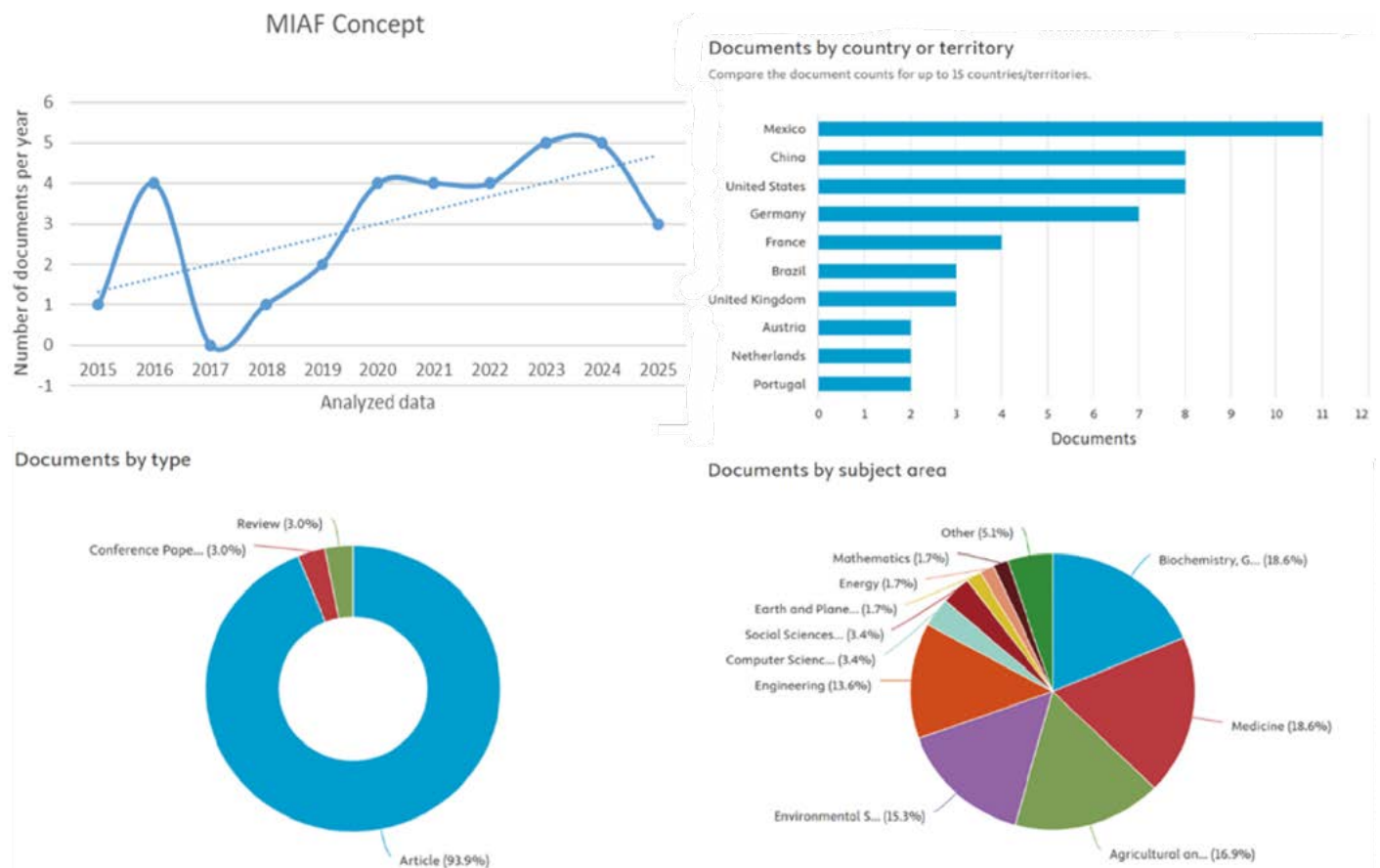


Figure 2. Metrics found on the Scopus platform with the word MIAF.

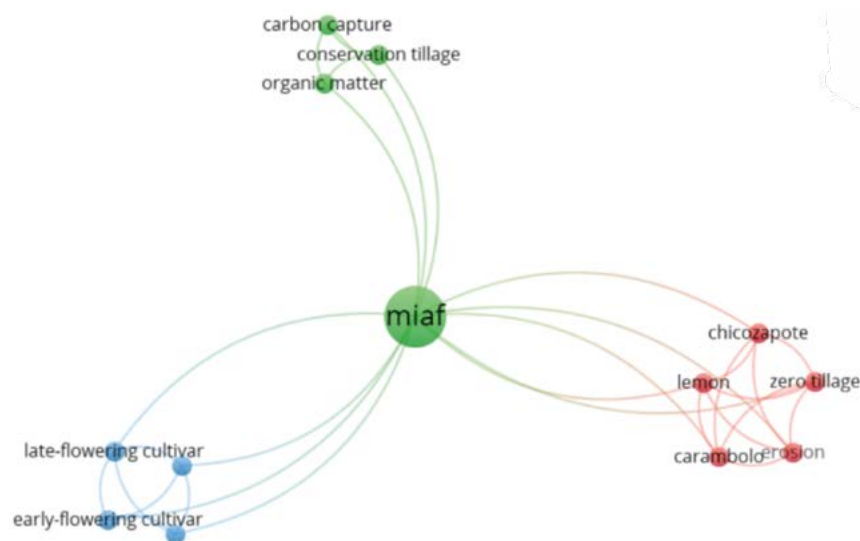


Figure 4. Bibliometric analysis of the concept Milpa Intercalada en Árboles Frutales (MIAF) generated with the VOSviewer program.

In this regard, the bibliometric analysis revealed that, around the concept of agroecosystems, the co-occurrence network is mainly concentrated in ecological dimensions, highlighting a focus on biological productivity, biodiversity, and ecosystem services. However, key terms such as public policies or family farming are notably absent, despite being essential for understanding the practical applicability and social viability of these systems particularly in highly vulnerable rural contexts (Wezel *et al.*, 2020). In the case of the MIAF concept, the predominant association with terms such as carbon sequestration underscores its potential contribution to climate change mitigation and environmental sustainability. Nevertheless, there remains a gap in its connection to socioeconomic categories such as profitability, technological adoption, or gender. The omission of these dimensions limits the construction of a comprehensive vision of the system and reduces the potential to generate public policy proposals that foster its scaling-up (Arriaga-Vázquez *et al.*, 2020). Within this framework, the use of bibliometric tools like VOSviewer constitutes a valuable strategy for identifying trends and patterns in scientific production; however, its scope must be complemented by qualitative and interdisciplinary approaches that allow for contextualizing the findings, interpreting knowledge gaps, and linking academic analysis with the real needs of agricultural systems (Van Eck & Waltman, 2017).

Disciplines and Activities that Must Be Implicit in the MIAF

Given that MIAF is considered a multi-objective system, Table 1 presents the main disciplines and activities that should be taken into account when studying the Intercropped Milpa System with Fruit Trees in Mexico. The integration of agroecological and traditional knowledge within the MIAF system stems from its combination of traditional agricultural practices with agroecological principles, promoting biodiversity, resilience, and sustainability. Its effective implementation depends on the collaboration of various

Table 1. Disciplines and activities to consider when studying the MIAF system in Mexico. Source: Prepared by the authors, August 2025.

No.	Discipline	Activities to be carried out in the MIAF system
1	Edaphology or soil science	<ul style="list-style-type: none"> • Generate nutritional doses for annual and perennial crops. • Analyze soil flora and fauna. • Conduct field and laboratory studies to analyze the physical, chemical, and biological properties of the soil. • Conduct research on soil formation processes, such as weathering, erosion, and sedimentation. • Evaluate soil fertility and its ability to support plant growth. • Study the impact of human activities on the soil, such as agriculture, deforestation, and pollution. • Teach soil science courses to producers, technicians, officials, and the general public on sustainable soil management practices. • Evaluate soil quality for agriculture, forestry, and construction. • Conduct environmental impact studies for development projects. • Participate in the development of public policies related to soil management, land conservation, and food security. • Promote the adoption of sustainable soil management practices among farmers and other land users. • Communicate the results of their research to the general public through articles, books, conferences, and presentations. • Raise public awareness about the importance of soil for life and the environment. • Promote public understanding of the challenges and opportunities related to sustainable soil management.
2	Agrology or crop science	<ul style="list-style-type: none"> • Techniques and methodologies for seedbed preparation and cultivation of annual and perennial crops. • Soil fertility management. • Weed control. • Water management. • Soil conservation. • Assessment and monitoring.
3	Agronomy	<ul style="list-style-type: none"> • Soil preparation (tillage, fertilization, and planting) • Crop management (irrigation, weed control, pest and disease control, pollination) • Harvest and post-harvest • Agricultural extension (technology transfer, training, and technical assistance) • Natural resource management • Plant physiology activities • Soil science activities • Plant breeding activities • Plant genetics activities • Agroecology • Improving annual and perennial cultivation techniques • Ensuring sustainable food production for MIAF families • Environmental protection and the well-being of rural communities
4	Agricultural entomology	<ul style="list-style-type: none"> • Insect identification and classification • Insect biology and ecology • Assessing damage to annual and perennial crops • Pest management strategies • Protecting MIAF crop yields • Preserving crop quality • Promoting sustainable agriculture
5	Phytopathology	<ul style="list-style-type: none"> • Disease diagnosis and identification • Pathogen biology and epidemiology • Pathogen-host interactions • Disease management strategies • Protecting crop health • Preserving biodiversity • Promoting sustainable agriculture

Table 1. Continues...

No.	Discipline	Activities to be carried out in the MIAF system
6	Weedology or Weed Science	<ul style="list-style-type: none"> • Weed biology and ecology • Weed damage • Agroecological weed control methods • Herbicide resistance • Sustainable weed management • Increasing agricultural productivity • Improving crop quality • Environmental protection • Developing new weed control and management strategies
7	Hydrology of water conservation or management	<ul style="list-style-type: none"> • Rainwater and irrigation monitoring • Development of water management plans • Implementation of strategies to reduce water consumption, improve water use efficiency, and protect water quality. • Educational programs to inform the public about the importance of water, the challenges of water management, and responsible consumption practices. • Awareness campaigns to raise awareness about the value of water, the need to conserve it, and ways to reduce individual and collective consumption. • Promoting the active participation of various stakeholders in water-related decision-making. • Development of efficient technologies to improve water use efficiency in various sectors, such as agriculture, industry, and domestic use. • Implementation of innovative solutions to address water management challenges, such as water reuse and rainwater harvesting.
8	Pomology	<ul style="list-style-type: none"> • Variety selection and evaluation (Varietal research, varietal trials, and variety recommendations) • Fruit tree propagation (Selection of propagation material, propagation techniques, and rootstock production) • Fruit orchard establishment (Site selection, soil preparation, and tree planting) • Fruit orchard management (Pruning, irrigation, fertilization, weed control, and pest and disease management) • Harvest and postharvest (Ripening, harvesting techniques, and postharvest handling)
9	Agricultural topography or soil conservation engineering	<ul style="list-style-type: none"> • Land slope analysis • Soil condition assessment • Identification of erosion problems • Design and construction of contour lines • Design and construction of terraces • Design and construction of levees • Monitoring the effectiveness of soil conservation works • Environmental impact assessment • Raising awareness about the importance of soil conservation • Training in soil conservation techniques
10	Post-harvest science and technology	<ul style="list-style-type: none"> • Maintain the quality of harvested products • Minimize harvest and post-harvest losses • Extend the shelf life of products • Add value to harvested products • Analyze post-harvest physiology • Combat post-harvest diseases and pests • Manage temperature, relative humidity, and packaging of MIAF products • Select the appropriate harvest time • Harvesting techniques • Protect and preserve harvested products • Prevention and treatment • Evaluation and control • Added value

Table 1. Continues...

No.	Discipline	Activities to be carried out in the MIAF system
11	Sociology	<ul style="list-style-type: none"> • Design and conduct research • Analyze data and interpret results • Teach sociology courses • Develop teaching materials • Supervise graduate students • Provide consulting services to organizations • Conduct social impact studies • Participate in social movements • Develop public policies • Write scholarly articles, as well as books and articles for the general public • Give lectures and presentations
12	Agricultural marketing or agricultural marketing	<ul style="list-style-type: none"> • Demand analysis • Opportunity identification • Product design • Brand and packaging development • Consumer communication • Demand stimulation • Supply chain management • Distribution channel development • Cost and competition analysis • Pricing strategies • Negotiation with buyers • Customer relationship development • Risk identification and assessment • Implementation of risk management strategies • Sustainable agricultural practices for marketing

disciplines such as agronomy, ecology, anthropology, and economics, among others enabling a comprehensive understanding and optimization of interactions among system components, including crops, fruit trees, and cultural practices. In this regard, the study of MIAF in Mexico represents a paradigmatic example of how interdisciplinary integration can enrich the understanding and improvement of sustainable agricultural systems, as this holistic approach is essential to addressing the contemporary challenges of rural agriculture in Mexico.

Systemic Thinking Theories Focused on the MIAF System

The open systems approach provides a valuable perspective for understanding the functioning of MIAF and its potential for sustainable agriculture, since by recognizing the dynamic interactions between system components and their environment, it becomes possible to design management strategies that promote food production, environmental conservation, and the well-being of rural communities. Moreover, MIAF is also an ancestral agricultural practice that combines the cultivation of maize, beans, and squash with the production of fruit trees, and has been recognized for its capacity to improve soil fertility, increase biodiversity, and provide food security in rural communities (Cortés-Flores *et al.*, 2012).

Table 2 presents the main theories conceptualized from a systems thinking perspective, which allow contextualization of how the Intercropped Milpa System with Fruit Trees (MIAF) can be analyzed as a complex system. This system is composed of various interconnected elements, including:

- Biological components: maize, beans, squash, fruit trees, soil, microorganisms, pollinating insects, and other organisms.
- Abiotic components: water, sunlight, temperature, soil pH, nutrients, and minerals.
- Socioeconomic components: agricultural practices, traditional knowledge, local markets, public policies, and community needs.

Systems thinking provides a theoretical framework for understanding the interaction between these components, evaluating not only the internal functioning of MIAF but also its impact on the environment and rural communities. In this way, these theories enable a comprehensive analysis of MIAF, taking into account its ecological, social, and economic dimensions, and facilitating the design of sustainable and resilient strategies for its management.

Table 2. Theories to consider when studying the Intercropped Milpa System in Fruit Trees (MIAF). Source: Prepared by the authors, August 2025.

Theory	Evidence / Case Studies	Benefits for the MIAF	Concrete examples
Open Systems	Cortés-Flores <i>et al.</i> , 2012; Gómez-Méndez <i>et al.</i> , 2014; Harvey <i>et al.</i> , 2014	It enables the exchange of energy, matter, and information; it promotes sustainability and food security.	Fruit trees fix nitrogen; crops provide organic matter; pollinators facilitate reproduction; interaction with climate and agricultural practices
Self-organization	Altieri, 2009; Gómez-Méndez <i>et al.</i> , 2014; Nicholls y Murren, 2010	It generates emerging patterns, resource efficiency, resilience, and adaptation.	Spatial distribution of trees and crops; competition for light and nutrients; feedback between growth and resource availability
Feedback	Capra, 2012; Gunderson y Holling, 2002; Altieri, 2009	It maintains stability, regulates processes, and optimizes productivity and sustainability.	Water and nutrient cycling; biological pest control; soil fertility dynamics; positive and negative loops
Synergy	Harvey <i>et al.</i> , 2014; Liniger <i>et al.</i> , 2015; Altieri, 2009; Gómez <i>et al.</i> , 2014	Maximizes ecological, social, and economic outcomes; improves sustainability, resilience, and multifunctionality	Improved soil fertility; natural pest control; biodiversity conservation; microclimate regulation; increased productivity
Resilience	Altieri y Nicholls, 2000; Jones <i>et al.</i> , 2008; Altieri, 2009	Shock absorption capacity, climate change adaptation, and food security	Crop and tree diversity; functional redundancy; feedback and learning; continuous production in the face of drought, flooding, or pests

CONCLUSIONS

This research broadens and contextualizes the concept of Agroecosystem, emphasizing the need to explicitly integrate social, cultural, political, and economic dimensions into its study, as these are essential for understanding productive systems such as MIAF. A total of 12 disciplines and their key activities for its management and sustainability were identified, along with five systemic theories that explain its integrated functioning laying the foundation for the design of public policies, multidisciplinary intervention strategies, and future applied research that prioritizes socio-environmental sustainability and the well-being of rural communities. Despite the methodological limitations inherent in its bibliometric and theoretical-descriptive approach such as dependence on specific databases (Scopus) and the limited volume of direct scientific output on MIAF this study highlights the system's potential as a sustainable alternative to improve soil fertility, productivity, and socio-ecological resilience in regions like Los Tuxtlas. Its practical applications include the design of public policies aimed at soil conservation, agricultural extension, and integrated rural development. However, it is recommended that future research adopt interdisciplinary approaches (with emphasis on socioeconomic and gender dimensions), experimentally evaluate long-term agronomic and environmental impacts, and explore adoption and scaling strategies involving active participation from producers.

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