Adaptation practices and challenges of the milpa intercropped in fruit trees (MIAF) system to cope climate change

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ABSTRACT

Objective: To describe and analyze the main practices and challenges associated with the Milpa Intercropped in Fruit Trees (MIAF) system in response to the climate variability due to climate change (CC) in the MIAF Module of San Andrés Tuxtla, Veracruz.

Methodology: A climatological analysis of the study area was conducted, along with a review of adaptation practices to climate change and the conceptual framework of the milpa system, climate change, and adaptation, using the Scopus platform. Review metrics and a bibliometric analysis were generated using VOSviewer.

Results: In the 1970s, maximum temperatures were lower as compared to the 1950s and 1980s. Four adaptation strategies implemented in the MIAF system in response to climate change were identified, focused on water management, biodiversity, agronomic practices, and the functionality of those strategies. A total of 12 relevant documents published between 2018 and 2022 were found, comprising 75% scientific articles, 16.7% essays, and 8.3% book chapters. The publications comes from Mexico, the United States, the United Kingdom, and Philippines. The predominant thematic areas were environmental sciences (30.4%), social sciences (26.1%), and agriculture (13.0%).

Conclusions: The study reveals a limited amount of literature on the subject. Furthermore, the MIAF system faces critical challenges, including the need to adapt traditional agricultural practices to increasingly extreme climatic conditions, the transfer of knowledge and adaptive technologies to rural communities, and the potential decline in crop yields due to fluctuations in temperature and precipitation.

Keywords: temperature, precipitation, terraces, soil, water.

INTRODUCTION

The Milpa Intercropped in Fruit Trees (MIAF) system was initially developed in 1988 by researchers from INIFAP and the Colegio de Postgraduados, incorporating the Live Wall Terrace (LWT) technology, which consists of *Gliricidia sepium* L. hedgerows reinforced by a runoff filter designed to impede free-flowing water and delineate strips for annual crops, gradually leading to terrace formation (Cortés-Flores *et al.*, 2007). After an

average of eight years, this technology proved to be effective for erosion control, retaining approximately 2 tons per hectare per year, and significantly reducing soil loss compared to traditional tillage systems, which can result in up to 146 tons per hectare per year of soil loss (Francisco *et al.*, 2006). In another study based on five years of observation, the average runoff coefficient decreased from 30% to 15% under both traditional tillage and LWT treatments. In this context, water erosion also entails the loss of organic matter and nutrients contained within sediments and surface runoff caused by rainfall. The organic matter, nitrogen, and phosphorus content in sediments collected from LWT systems was higher than that of traditional systems. However, due to the greater volume of sediment in traditional systems, overall nutrient loss was significantly higher (Turrent, 1995). Organic matter loss reached values of 600 and 3,400 kg ha^{-1}, while potassium, calcium, and magnesium base losses through runoff were between 37 and 66 kg ha^{-1} for both treatments. In terms of productivity, the LWT system achieved higher annual maize yields (4.95 t ha^{-1}) with acceptable yield stability, whereas the traditional tillage system had lower productivity (4.12 t ha^{-1}) and less stable yields (Turrent, 1986). Continuous maize cultivation across 13 cycles and terrace formation led to a slight decline in soil fertility, reflected in a pH reduction of 0.43 units, a decrease in organic matter by 0.56%, and reductions in exchangeable potassium and calcium by 0.15 and 3.08 c mol kg^{-1} of soil, particularly in the upper parts of the terrace. Building on this experience, INIFAP and the Colegio de Postgraduados developed the MIAF system in 2003 as a technological evolution for small-scale production units. This system sought to recover the core elements of the traditional milpa paradigm while integrating principles from classical agronomic science. MIAF combines strategies and components designed to control soil erosion and improve soil quality, and it is considered a viable alternative for smallholders to enhance household income (González & López, 2023). The system consists of three intercropped species: a fruit tree (epicrop), maize (mesocrop), and beans or another edible legume (undercrop), in an intensive agronomic interaction that optimizes land use spatially and temporally (Pérez & Martínez, 2022). It is also regarded as a multi-objective or multipurpose technology aimed primarily at increasing net income and family employment, protecting soil against water erosion, fostering synergistic interactions among component crops to improve natural resource use, and increasing carbon capture. It is important to note that the system is inherently complex, requiring a range of technical skills grounded in agronomic knowledge of the soil-plant-atmosphere relationship. Furthermore, climate change presents a significant challenge for tropical fruit production not only under the MIAF system but also in commercial plantations in temperate and tropical climates as it poses a risk of yield reduction, fruit damage, and even threatens the productive viability of certain crops (IPCC, 2019; FAO, 2021). Given these concerns, the objective of this research was to describe and analyze the primary practices and challenges that the MIAF system faces in response to climate change variability. MIAF was originally proposed as a sustainable alternative for hillside agriculture, offering benefits such as erosion control, improved soil quality, and enhanced biodiversity. However, climate change introduces a new threat to the system's viability, making it imperative to assess its potential impacts and develop effective adaptation strategies.

MATERIALS AND METHODS

Study area

The MIAF Module, officially named the "Research and Technology Transfer Module for Productive and Conservationist Agriculture Dr. Antonio Turrent Fernández" (MIAF-INIFAP Module), is located in the community of Axochio, municipality of San Andrés Tuxtla, Veracruz, at an altitude of 60 meters above sea level, with coordinates 18° 20' 0.5" N and 95° 17' 57.7" W. Los Tuxtlas region is characterized by a warm sub-humid climate with summer rainfall (Aw2) (García, 1981), and annual precipitation ranges between 1,500 and 2,000 mm. Geomorphologically, the area consists of rolling hills with slopes ranging from 10% to over 20%. The soils have developed through alluvial sediment deposition and volcanic activity (Comisión del Papaloapan, 1972).

Information search

This phase involved a state-of-the-art analysis focused on the conceptual triad MILPA-CLIMATE CHANGE-ADAPTATION. The search was conducted on the Scopus platform, filtering by title, abstract, and keywords.

Information analysis

A metric analysis was carried out considering publication year, country, language, discipline, and document type. Additionally, a bibliometric analysis was conducted using VOSviewer, a software tool developed by the Center for Science and Technology Studies (CWTS) at Leiden University, specifically designed to visualize bibliometric networks (Van Eck & Waltman, 2010). This tool was used to generate visual maps that represent bibliographic connections among the documents retrieved from the Scopus database (Guallar *et al.*, 2020).

Considerations for comprehensive assessment of climate change impact on the MIAF system

Assessing the impact of climate change on the MIAF system is essential to ensuring its long-term viability and supporting the adaptation of hillside agriculture to changing climatic conditions (IPCC, 2021). This type of approach provides a comprehensive framework for evaluating impacts, identifying adaptation strategies, and monitoring the performance of the MIAF system within the context of climate change, as outlined below (FAO, 2022).

RESULTS AND DISCUSSION

Historical Behavior of Climatic Variables in the Region of Axochio, San Andrés Tuxtla, Veracruz

Climate change poses a significant challenge to tropical fruit production worldwide, as variations in temperature, precipitation, climate patterns, and extreme weather events can adversely affect several agricultural factors, including yield and fruit quality, pest and disease incidence, water availability, and pollination processes. In this context, Figure 1 illustrates the behavior of maximum and minimum temperatures from 1951 to 1981,

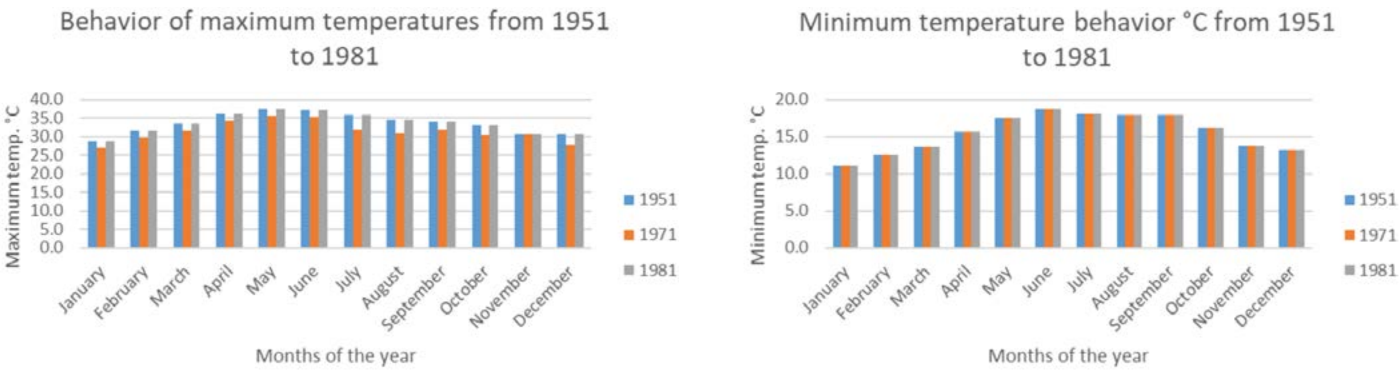

Figure 1. Behavior of maximum temperatures (left side) and minimum temperatures (right side) based on data from the Sihuapan station, municipality of San Andrés Tuxtla, Veracruz.

based on data recorded at the National Meteorological Service (SMN) station located in the community of Sihuapan, municipality of San Andrés Tuxtla, Veracruz. Notable variations in maximum temperatures were observed in 1951 and 1981 when compared to the 1971 data. However, with respect to minimum temperatures, no significant changes were recorded in any of the years analyzed.

Muller *et al*. (2011) report that elevated temperatures can reduce flowering, pollination, and fruit filling, ultimately leading to lower yields. Additionally, high temperatures may impair fruit development and quality by causing premature ripening, reduced size and flavor, and increased susceptibility to disease. Likewise, Lobell and Burke (2010), in their study of changing temperature, precipitation, and humidity patterns, found that these variations can promote the proliferation of pests and diseases, increasing both their incidence and severity. Certain pests and pathogens are particularly sensitive to specific climatic changes, which can alter their geographic distribution and life cycles. Regarding precipitation trends, Figure 2 illustrates the behavior of this climatic variable, showing that from August to November in the years 1951 and 1981, precipitation levels were

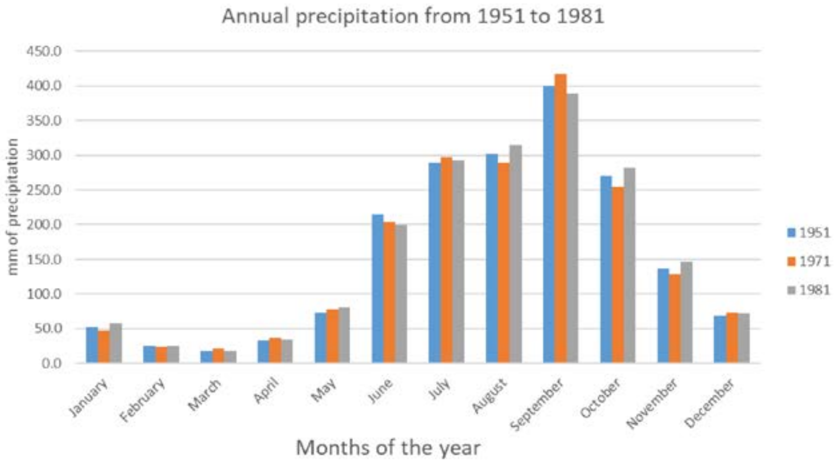

Figure 2. Precipitation patterns from 1951 to 1981 based on data from the SMN station in Sihuapan, San Andrés Tuxtla, Veracruz.

notably higher as compared to 1971. These years recorded greater rainfall in the region. In this context, Giuliani and Zwane (2016) identified that water stress induced by climate change primarily resulted from rising temperatures and increased evapotranspiration, along with altered precipitation patterns. This led to greater water stress in crops, negatively affecting their growth, development, and productivity. Water scarcity, in turn, limited agricultural output, especially in arid and semi-arid regions. Finally, Aizen *et al.* (2009) revealed that climate change can significantly affect the distribution, abundance, and activity of pollinators such as bees and bats. This has direct implications for the pollination of tropical fruit crops, compounded by biodiversity loss and pesticide use both additional factors contributing to pollinator decline.

At the center of the diagram is the MIAF system, surrounded by a series of adaptation strategies grouped into four key categories: water management, biological diversity, management practices, and functional strategy roles. The diagram highlights principal practices such as crop diversification, the use of resilient varieties, rainwater harvesting, and agroforestry, among others, showing how they interconnect to support adaptation efforts.

This framework serves as a key tool for understanding and addressing the challenges posed by climate change globally. Moreover, it offers not only a comprehensive approach for tackling these challenges in agricultural and rural systems, but also acts as a bridge between theoretical understanding and practical implementation promoting sustainable and scalable solutions.

Sustainable water management includes techniques such as rainwater harvesting, drip irrigation, and soil moisture conservation through mulching or vegetative ground cover. Mahato (2014) and Ravishanker *et al.* (2013) found these practices effective in enhancing crop resilience in regions vulnerable to climate change, as demonstrated in studies conducted in Sub-Saharan Africa and South Asia.

Crop diversification and agroforestry systems involve integrating drought- or pest-resistant crops, intercropping different varieties, or implementing agroforestry systems that strengthen the resilience of agricultural systems. This approach helps stabilize farmers' incomes and preserve biodiversity (Tiamiyu *et al.*, 2017; Mugagga *et al.*, 2019).

Genetic improvement and crop selection focus on developing varieties that tolerate climate-related stress, such as drought or salinity critical strategies for preserving plant and animal species. Research by Hu *et al.* (2017) and Waongo *et al.* (2015) emphasizes the importance of improving seeds and germplasm to cope with climate change.

Soil conservation practices such as terracing, live barriers, crop rotation, and organic fertilization are not only effective in reducing erosion but also in enhancing soil fertility and quality. These techniques have been validated in highly agriculture-dependent countries like Ethiopia and Nigeria (Wolka & Zeleka, 2017).

Integration of climate-smart technologies involves implementing climate monitoring, early warning systems, and digital tools for crop management, enabling farmers to make informed, proactive decisions that reduce negative impacts. According to FAO (2013) and De Pinto *et al.* (2020), Climate-Smart Agriculture (CSA) encompasses practices that enhance agricultural productivity while reducing greenhouse gas emissions.

Capacity building and infrastructure development entail training farmers in resilient practices and investing in climate-adaptive infrastructure such as flood-resistant rural roads, while strengthening the response capacity of farming communities (Asrat & Simane, 2018).

Livelihood diversification encourages engagement in non-agricultural activities such as small enterprises or agricultural insurance schemes designed to reduce economic risk identified as key strategies for ensuring food security under extreme climatic conditions (Fosu-Mensah *et al.*, 2010).

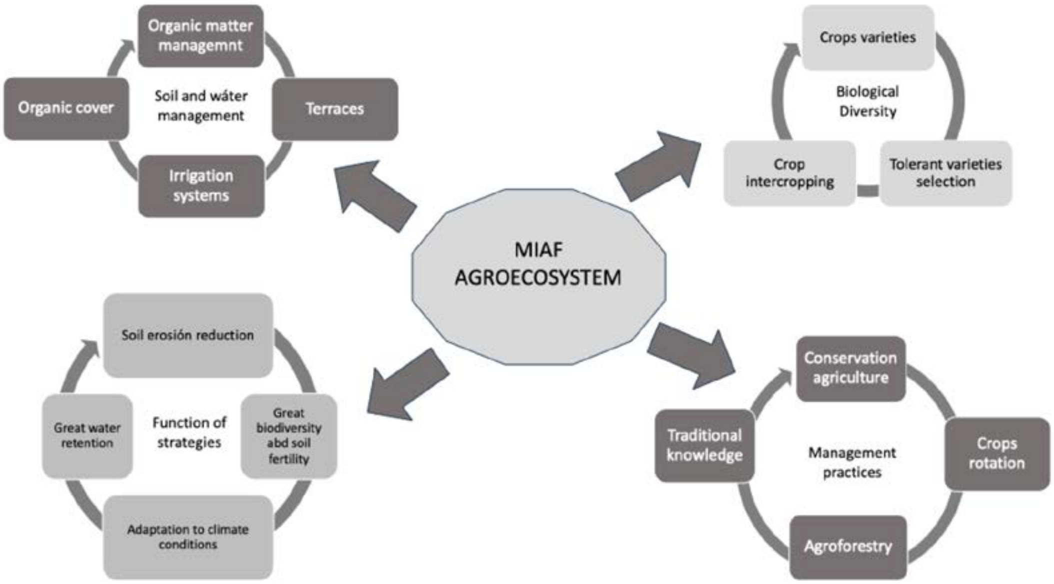

Figure 3. The Milpa as a climate change adaptation strategy practice. Source: Self elaboration.

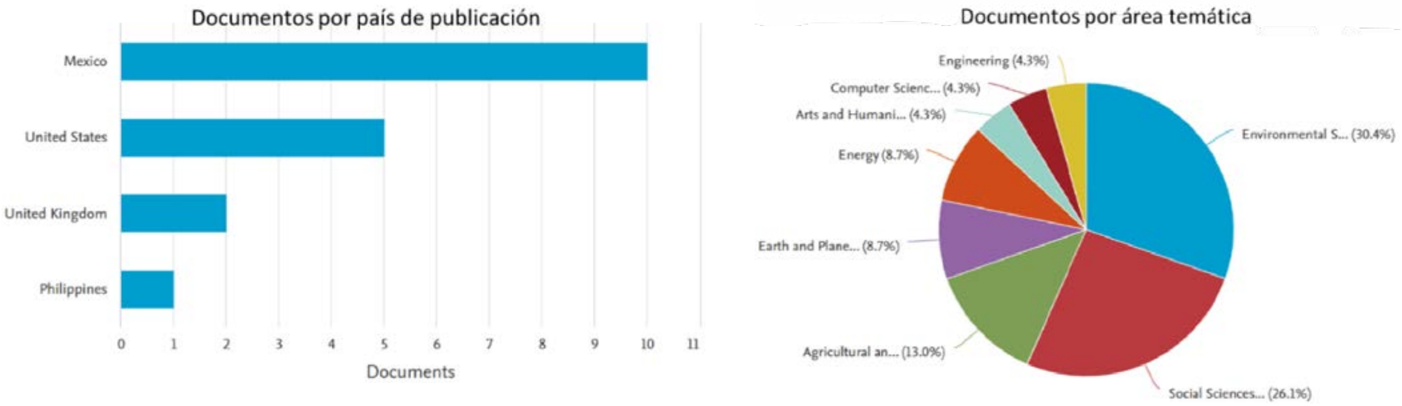

Figure 4. Documents by country of publication (left side) and documents by thematic area (right side) related to the concepts of milpa, climate change, and adaptation.

The following presents the results of the bibliometric analysis of the concepts Milpa-Climate Change and Adaptation, conducted using the Scopus database. A total of 12 documents were identified, published between 2018 and 2022 (2018: 1 article; 2020: 3 articles; 2021: 6 articles; and 2022: 2 articles). Of these, 75% were scientific articles, 16.7% were essays, and 8.3% were book chapters. The main findings from the identified metrics are summarized below.

Figure 5 illustrates the relationships identified among the keywords related to milpa, climate change, and adaptation. A strong interconnection is observed among these terms and the countries associated with them.

Main adaptation practices to climate change

Table 1 outlines a range of adaptation strategies designed to support producers working within the MIAF system in addressing the challenges posed by climate change (CC) and ensuring the sustainability of their production systems. It is essential to emphasize that climate change adaptation requires a comprehensive approach that integrates multiple strategies and actively involves all stakeholders in the fruit value chain. According to Siam *et al.* (2019) and Salazar *et al.* (2018), various adaptation practices have been developed to help producers of tropical fruit trees increase the resilience of their orchards and maintain sustainable production.

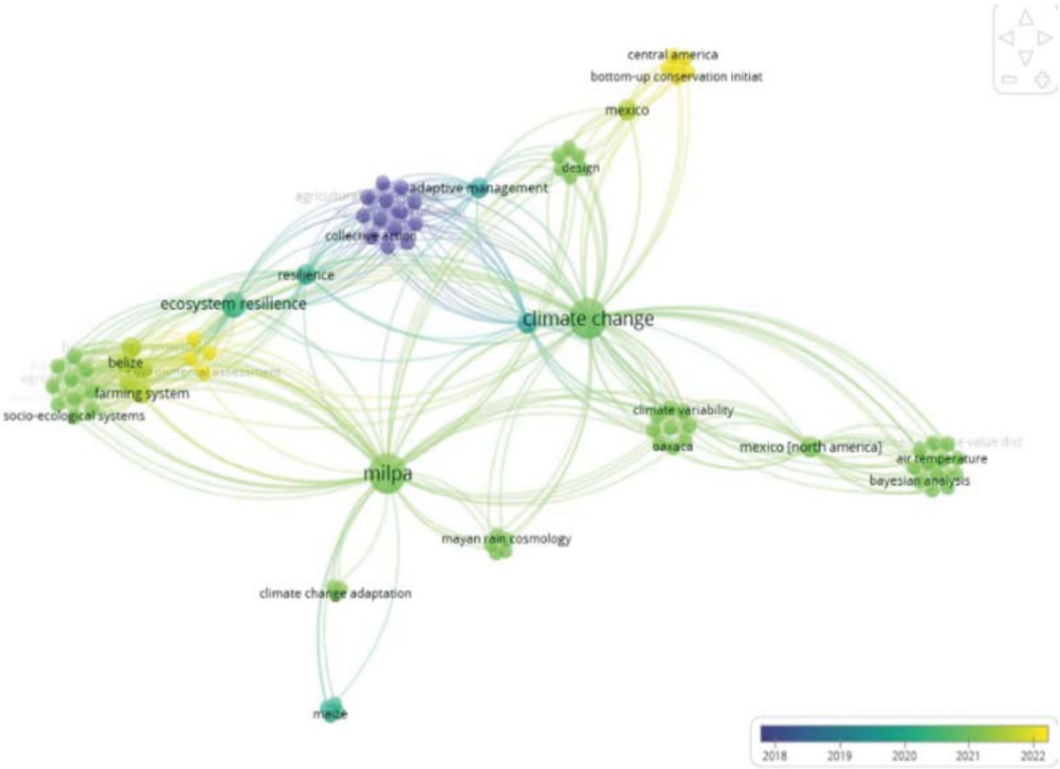

Figure 5. Nodes and links of the bibliometric analysis generated with the keywords milpa, climate change and adaptation.

Table 1. Adaptation strategies within the MIAF system to address climate change challenges.

Adaptation Practices for the MIAF System	Description
Selection of resistant varieties	• Use of stress-tolerant varieties: Selecting cultivars resistant to abiotic and biotic stress factors associated with climate change such as increased temperatures, drought, salinity, flooding, pests, and diseases is essential for adaptation. An example is the use of drought-tolerant mango varieties, which has proven to be an effective strategy for improving water productivity and yield under dry conditions (Mekuria *et al*., 2015; Salazar *et al*., 2018). • Diversification of fruit tree varieties: Incorporating varieties with different maturation periods and stress tolerance levels helps mitigate the risk of total crop loss due to extreme weather events. For instance, the diversification of rambutan varieties has shown to enhance orchard resilience to climate change in Thailand (Siam *et al*., 2019). • Prioritization of research and development: Emphasizing the breeding of new varieties with higher climate resilience and encouraging the exchange of genetic material across regions are critical to broadening the available genetic base and strengthening adaptation capacity.
Water management	• Improve irrigation efficiency through drip or micro-sprinkler systems to reduce water use and enhance water productivity, especially under drought conditions. According to FAO (2020), “Drip irrigation has proven to be an effective strategy, reducing water consumption by 40% and increasing banana yield by 20% under drought conditions.” • Rainwater harvesting during the rainy season serves as an alternative water source for irrigation during the dry season, reducing reliance on scarce surface or groundwater sources. For example, Mekuria *et al.* (2015) found that rainwater harvesting increased water availability for irrigating fruit trees by 50% in areas with seasonal rainfall. • Implement soil management practices that improve moisture retention and reduce erosion, such as the application of organic fertilizers, mulching, and minimum tillage. • Utilize treated wastewater for irrigation when it meets appropriate quality standards, providing an additional water source while promoting resource reuse.
Soil management	• Improve soil quality by adopting agricultural practices that enhance soil health, such as adding organic matter, reducing tillage, and using organic fertilizers. These practices increase the soil’s water-holding capacity, improve plant nutrition, and boost drought resilience. According to Jones et al. (2017), compost application has been shown to increase soil water retention by 15% and mango yield by 10%. • Soil conservation through the implementation of techniques such as vegetative cover and terracing helps reduce erosion caused by heavy rainfall, maintaining soil fertility and productivity. Pinho *et al.* (2014) reported that vegetative cover effectively reduced soil erosion by 50% and increased pineapple yield by 15%.
Crop management	• Establish plantations in areas with microclimates more favorable to climate change, such as shaded slopes or zones with greater water availability. • Implement practices to capture rainwater and/or retain soil moisture. • Adjust planting and harvesting dates according to shifting climatic patterns. • Prune trees to improve ventilation and sunlight penetration, reducing the incidence of disease. • Apply fertilizers and pesticides efficiently and sustainably, following technical recommendations and using low-impact environmental products (Junqueira *et al*., 2017). • Establish a monitoring system to assess the impact of climate change on the MIAF system over time. • Evaluate the effectiveness of implemented adaptation strategies and make adjustments or modifications as needed.

Table 1. Continues….

Adaptation Practices for the MIAF System	Description
Crop diversification	• Include other fruit species in production systems that are more tolerant to environmental stress conditions. • Combine fruit trees with other crops such as legumes or cereals to enhance soil fertility and reduce dependence on external inputs. • Establish agroforestry systems that integrate fruit trees with timber species and other vegetative components.
Capacity building	• Train tropical fruit producers in practical techniques for climate change adaptation. • Promote the exchange of information and experiences between producers and technical experts. • Encourage research and development of appropriate technologies for climate change adaptation in tropical agriculture. • Develop public policies that support the implementation of adaptation strategies in the fruit production sector.
Research and development	• Invest in research and development of new technologies for climate change adaptation in tropical agriculture • Encourage collaboration among researchers, extension agents, and producers to develop solutions tailored to local conditions • Prioritize research on the impacts of climate change on different tropical fruit species • Evaluate the effectiveness of various adaptation strategies in different contexts; use climate models to project future changes in variables such as temperature, precipitation, and evapotranspiration in MIAF-implemented areas • Incorporate crop impact models to assess the effects of climate change on the yields of MIAF crops (maize, beans) (CIMMYT, 2021; Morris & Scholes, 2022) • Identify and evaluate potential adaptation strategies for MIAF, such as selecting stress-tolerant varieties, implementing soil and water management practices, and diversifying crops • Analyze the economic and social feasibility of proposed adaptation strategies • Ensure farmer participation in the evaluation and adaptation process • Consider hydrological models to assess the impact of climate change on soil erosion and water availability

CONCLUSIONS

The MIAF system is a resilient alternative to cope climate change, combining practices such as crop diversification, water management, and soil conservation to enhance agricultural productivity. However, it still faces challenges, including adaptation to extreme climates, technology transfer, and potential reductions in crop yields. Strategies such as the use of resistant varieties, rainwater harvesting, agroforestry, and soil conservation are essential to strengthen its resilience. In this context, it is crucial to promote research, train producers, and develop public policies that support the adaptation of MIAF to climate change. Climate change adaptation practices offer multiple advantages for tropical agriculture by helping producers increase the resilience of their cropping systems, improve productivity and crop quality, and ultimately contribute to food security and the sustainable development of agroecosystems.

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