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COMPARISON BETWEEN TROPICAL AGROECOSYSTEMS AND TEMPERATE AGROECOSYSTEMS

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Abstract: This literature review analyzes the differences and similarities between temperate and tropical agroecosystems. The first parts address systems theory and the components of systems in order to understand the concept of ecosystem, from which the concept of agroecosystem originates. The second part addresses the concept of agroecosystem in its entirety, its subsystems and its limits, as well as the concepts of sustainability and sustainability to understand the functioning and management of agroecosystems. Finally, the characteristics, history, evolution, crops, and different management practices of agroecosystems in tropical and temperate regions are analyzed. In addition, a comparison of both types of agroecosystems was made to understand their similarities and differences within the framework of agroecosystems, their subsystems, and their limits.

INTRODUCTION

The concept of agroecosystem has been a pillar in the analysis of agricultural systems, where the interactions between natural and sociocultural elements in a given space are recognized. This vision is complemented by the general systems theory (GST) developed by Ludwig von Bertalanffy, which proposes that systems are an organized whole where their parts interact in such a way that they generate a functionality greater than the sum of their constituent elements (Zhang & Ahmed, 2020). In this context, agroecosystems represent open and dynamic units, composed of subsystems such as human, productive, and semi-natural, which constantly interact to maintain agricultural sustainability and productivity (León-Sicard et al., 2018). The interdependence between these components is essential for the management and success of agricultural systems, especially in tropical and temperate regions. Tropical regions, with their high biodiversity, have witnessed the transformation of natural ecosystems into agroecosystems, influenced by history and agricultural practices such as the Green Revolution, which intensified agricultural production at the expense of biodiversity (Perfecto & Vandermeer, 2008). In contrast, temperate agroecosystems present a different environment, characterized by climatic seasonality and an agricultural approach geared toward the production of highly mechanized annual monocultures (Nair et al., 2021). Despite climatic differences, both types of agroecosystems face similar challenges in terms of biodiversity conservation and ecological balance, highlighting the importance of sustainable practices to ensure their long-term functionality.

INTRODUCTION TO GENERAL SYSTEMS THEORY

The term system has its roots in the Greek word sýstēma, which means "an organized whole." Today, it is understood as a set of interacting parts or elements that generate greater functionality than the sum of their components (Zhang & Ahmed, 2020). General Systems Theory (GST) was proposed by Ludwig von Bertalanffy in the 1920s with the aim of developing theoretical models that would connect different areas of knowledge. This approach sought to avoid duplication of effort in the study of similar phenomena and to promote the creation of theories applicable to multiple disciplines. GST is based on isomorphisms, which are structural similarities between systems from different disciplines that are initially unrelated (Carr-Chellman & Carr-Chellman, 2020; von Bertalanffy & Sutherland, 1974). In 1969, von Bertalanffy argued that natural systems are open, as they exchange matter and energy with their environment. These dynamic systems have the ability to achieve and maintain equilibrium under conditions of constant exchange. In addition, he proposed the principle of equifinality, according to which open systems can reach the

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same final state regardless of their initial conditions. His theory encouraged an interdisciplinary approach to the creation and application of scientific knowledge (von Bertalanffy & Sutherland, 1974; Zhang & Ahmed, 2020).

THE LINK BETWEEN ECOLOGY AND ECOSYSTEM

The concept of ecology was introduced in 1866 by Ernst Haeckel to describe the scientific study of living beings and their interactions with the abiotic environment. This discipline emphasizes the interdependence between living organisms and inert elements, such as soil and climate, through the exchange, recycling, and transformation of matter and energy (Caporali, 2021; Inogwabini, 2019; Skene, 2024). In 1935, Arthur Tansley coined the term ecosystem to define the basic unit of nature. This concept revolutionized ecology by emphasizing that biotic and abiotic components must be studied as an integrated system. Eugene Odum later consolidated this vision by pointing out that these elements are interconnected and cannot be analyzed separately. Thus, an ecosystem is defined as an open system where living organisms and environmental factors interact in a given space (Cook, 2021; Lefroy, 2022; Yu et al., 2021).

THE AGROECOSYSTEM: CONCEPT AND COMPONENTS

An agroecosystem (AE) is a unit of analysis in which natural and sociocultural elements interact within defined geographical boundaries. This open, h y system combines ecosystem processes with cultural and economic interactions, with the main objective of agricultural production. In its internal structure, biodiversity spaces, productive areas, and cultural aspects are connected, forming a complex and dynamic network (León-Sicard et al., 2018; Toro-Mujica et al., 2011) as shown in **Figure 1.** The agroecosystem is composed of three main subsystems: Human subsystem: Represents the central control of the system. It includes infrastructure, sociocultural practices, and decision-making related to agricultural management. This subsystem guides productive activities and coordinates interaction with the environment. Productive subsystem: This is made up of the plant and animal species that the human subsystem introduces for productive purposes. These species, known as agrobiodiversity or planned biodiversity, are deliberately selected to fulfill specific functions in the system. Semi-natural subsystem: This comprises the native biodiversity that persists in the environment. This associated biodiversity performs essential ecological functions, such as recycling materials and transforming energy, and operates independently of human control. Together, these subsystems interact to maintain the ecological balance and sustainability of the agroecosystem, integrating biological, cultural, and economic elements in a dynamic context (Hatt & Döring, 2023; Liu et al., 2022; Perfecto & Vandermeer, 2008).

TROPICAL ECOSYSTEMS AND AGROECOSYSTEMS

Tropical regions have been inhabited and used for agriculture for approximately 10,000 years. Originally, tropical agroecosystems were characterized by agroecological practices that respected native biodiversity, including the integration of tree species. However, the arrival of imperial and colonial systems in the 17th and 18th centuries dramatically transformed tropical landscapes. Large areas of natural ecosystems were converted to monocultures for the export of agricultural products to temperate regions (Janzen, 1973). In the 20th century, the Green Revolution further intensified production in the tropics through the introduction of hybrid seeds, agrochemicals, and modern technologies. Today, tropical landscapes combine extensive

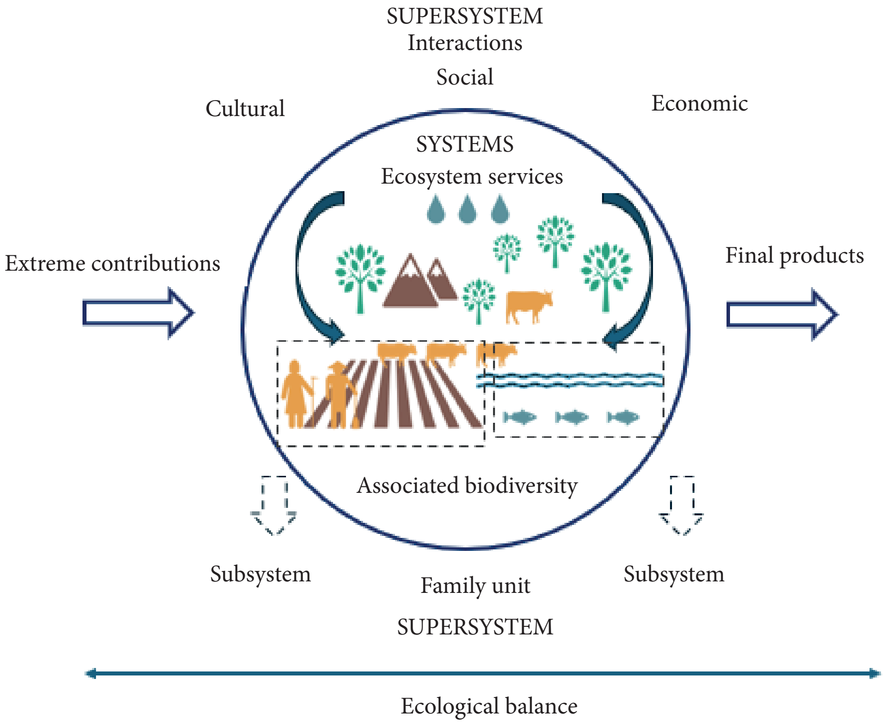

Figure 1. Schematic model of an agroecosystem as an integrated system (Source: own elaboration).

areas of monoculture, medium- and small-scale agroecosystems, and fragments of native ecosystems. These areas face ecological and economic challenges due to pressure to increas l productivity without compromising biodiversity and ecosystem services (Perfecto & Vandermeer, 2008).

The tropics are the regions of the planet between the Tropic of Cancer and the Tropic of Capricorn, located at 23° 27' north and south latitude, respectively (Gepts, 2008). These areas receive perpendicular sunlight throughout the year, concentrating a greater amount of thermal energy compared to temperate regions, where the sun's rays strike obliquely. This constant exposure generates average temperatures of 26°C, ranging from 23 to 35°C, and gives rise to a diversity of ecosystems ranging from rainforests to deserts and snow-capped mountains (Beck, 2019; Benbow & McIntosh, 2009; Roxburgh & Noble, 2001).

Unlike temperate regions, the tropics are characterized by the absence of a cold season. Seasonal fluctuations in temperature and solar radiation are minimal, significantly reducing the influence of seasonality on biological activity (Osborne, 2012). According to Gepts (2008), different climatic and ecological patterns occur in tropical and subtropical ecozones. The subtropics with winter rains, located between 30° and 40° latitude, have rainy winters with precipitation between 300 and 800 mm and dry summers. This ecozone, known as Mediterranean, is characterized by average monthly temperatures above 18°C for at least four months. Its vegetation includes trees, shrubs, hemicryptophytes, geophytes, and therophytes, and its importance lies in its role as a global producer of fruits and vegetables. In contrast, the subtropics with year-round rainfall represent 4% of the land mass and are found in southeastern America, Africa, Asia, and Australia. These areas are characterized by average temperatures above 18 °C and regular rainfall. The dry subtropics and tropics cover 21% of the Earth's surface, located in high-pressure belts that generate arid ecosystems with scarce rainfall.

Due to the combination of climatic and geographical variations, the tropics are home to an exceptional diversity of flora and fauna. Although humid forests are the most common ecosystems, these regions also include deserts, savannas, and mountain ecosystems, making them areas of high biodiversity and crucial importance for global ecological balance. The adjacent subtropical zones, although less climatically consistent, function as transition areas to temperate ecosystems and share some characteristics with the tropics (Osborne, 2012; Gepts, 2008).

Figure 2. Model of a typical tropical agroecosystem in Mexico located in the high mountains of the state of Veracruz.

INTERACTION BETWEEN BIODIVERSITY AND AGRICULTURE IN THE TROPICS

The tropics are home to approximately 80% of the planet's terrestrial species, concentrated especially in humid areas. Tropical rainforests stand out as the most biodiverse terrestrial ecosystem, harboring 66% of the 250,000 plant species and 90% of the insect species estimated worldwide (Sánchez, 2019). This extraordinary biological diversity is largely attributed to the high specialization of tropical species, whose ecological interactions are more interconnected compared to other regions (Sheldon, 2019).

Six key regions have been identified as the main areas of origin of agriculture, including Mesoamerica, the Fertile Crescent (comprising Mesopotamia, the Levant, Turkey, and western Iran), northern China, the Andes and surrounding areas in South America, the Sahelian and Sudanese savannas in Africa, and a large Asian region including India, Indochina, and New Guinea. These areas, predominantly located in tropical and subtropical ecozones, were instrumental in the domestication of crops thanks to their enormous biodiversity. The biological abundance of these regions made it easier for early farmers to identify and domesticate plants adapted to diverse climatic and ecological conditions. Tropical and subtropical regions were not only fundamental to the development of crops, but also to their expansion, contributing significantly to the emergence of global agriculture (Gepts, 2008).

In tropical agroecosystems, the interaction between natural and productive elements is essential to ensure their sustainability. Native ecosystems provide key services such as pollination, seed dispersal, and nutrient recycling. However, the advance of intensive agricultural systems has compromised these functions, particularly in areas where agricultural practices do not consider ecological resilience. In this context, approaches such as island theory have emphasized the importance of conserving biodiversity in tropical landscapes to preserve ecosystem stability and functionality (Beck, 2019; Benbow & McIntosh, 2009).

Tropical agroecosystems, due to the levels of humidity present and high temperatures, have a higher rate of decomposition. This makes nutrient recycling faster and longer during the year, as conditions are ideal. On the other hand, and thanks to high levels of rainfall, they have less fertile soils compared to soils in temperate regions. This occurs due to the leaching of nutrients that takes place during rainy seasons, which is more pronounced in monsoon regions. For this reason, soil nutrient reserves are low and require greater replenishment, especially nitrogen (Brady & Weil, 2016; Robertson & Vitousek, 2009).

TEMPERATE AGROECOSYSTEMS

The temperate regions of the planet are those located between the tropical and polar regions. A region can also be considered temperate if it has at least one month of frost with an average temperature range between -3 and 18 °C in the coldest month, and at least four months with an average temperature above 10 °C. The types of climates found in these regions differ in the northern zone, with boreal, continental, and oceanic climates, and in the southern zone, with subtropical and Mediterranean climates. These regions have marked seasonal climates between the warmest and coldest months, with precipitation throughout the year. Therefore, there are crops that can only be produced in one season, and the quantity of these is lower than in tropical regions (Nair et al., 2021; Silander, 2001).

Developed countries such as the United States, Canada, European countries, and New Zealand, which are located in temperate regions, have influenced the organization and practices of temperate agroecosystems. Historically, small production units have been and continue to be the dominant agroecosystem in these regions. However, in the 20th century, there has been an increase in large-scale family, communal, or corporate agroecosystems, where a few high-value crops are produced with high levels of mechanization for sale in local or foreign markets (Nair et al., 2021).

As indicated above, biodiversity in the tropics is greater than in temperate zones (Figure 3) and for this reason, in temperate zone agroecosystems, annual monoculture production with a high level of mechanization is more common. One of the factors limiting biodiversity in these areas is the climatic conditions, where there are distinct seasons and where winter is often accompanied by frost. This limits year-round production and only allows certain plant and animal species to be produced at certain times of the year. In addition, frost is a barrier to biodiversity and crops. This significantly affects the presence and pressure of pests in the system, as they may be less important because their cycle is interrupted in winter, but there may also be outbreaks with rapid development during productive seasons (Landis et al., 2000; Power, 2010).

This also gives rise to agricultural practices such as crop rotation to incorporate nutrients into the soil and improve its quality. Another practice characteristic of temperate zones is cover crops during times of the year when crop production has ended. These crops serve to cover the soil and prevent erosion, improve soil fertility, and increase post-harvest biodiversity. Finally, flowers or other plant species can be added to increase the presence of beneficial organisms, such as pollinators, as these also decline in winter (Landis et al., 2000; Tscharntke et al., 2012).

Nutrient recycling in temperate agroecosystems is slower than in tropical ones due to lower temperatures and lower rainfall. On the other hand, nutrient reserves and the amount of organic matter in temperate soils are greater, as rain does not leach the soils. As for the availability of these nutrients, they may not always be available due to frosts and may only be available until spring, which is part of the seasonality and climate of temperate zones (Brady & Weil, 2016; Robertson & Vitousek, 2009).

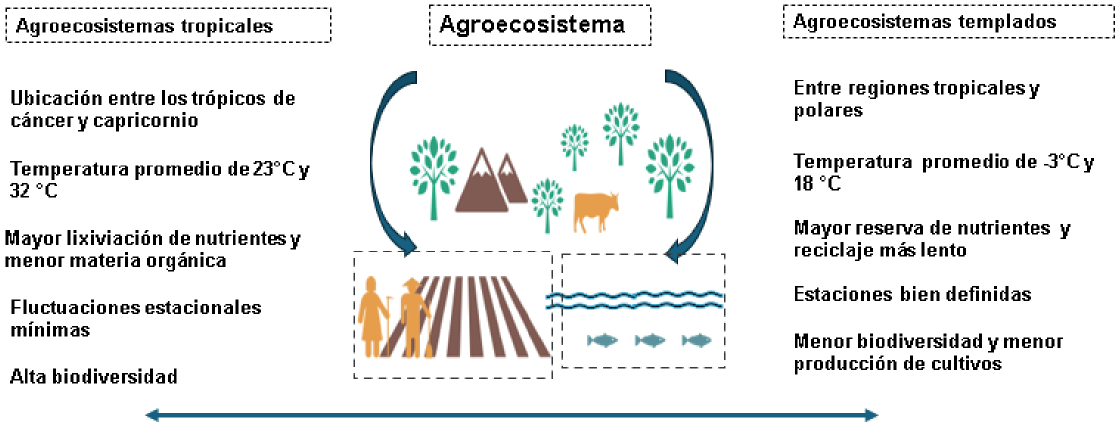

Figure 3. Schematic representation of the differences between tropical agroecosystems and temperate agroecosystems.

LIMITS OF AGROECOSYSTEMS

A systemic approach allows us to accept that agroecosystems are not static: their boundaries are dynamic and change according to internal pressures, such as the intensification of agriculture, and external factors, such as climate change and globalization. For example, in tropical agroecosystems, boundaries are determined by the fragility of their soils and the high pressure on their biodiversity. In contrast, temperate agroecosystems must adapt to marked seasonal cycles and growing technological demands. From this perspective, understanding the limits of an agroecosystem involves studying how subsystems (such as soil, water, plants, and human communities) interact to maintain the harmony of the system (Kemanian et al., 2024).

To ensure sustainability, it is necessary to respect certain natural boundaries and, consequently, impose certain limits. Two key indicators that translate sustainability into a graphical and measurable format are the "ecological footprint" and "planetary boundaries." Planetary boundaries represent a comprehensive and simple tool for assessing the health of our planet. In this context, four processes (climate change, biochemical flows, Earth system change, and biosphere integrity) have already exceeded thresholds that can lead to dangerous levels of instability in the Earth system and increased risk to humans (Pinto, 2019).

Carrying capacity is often used as a concept to justify natural resource management, but it also serves as the basis for neo-Malthusian arguments related to the availability of global resources versus population growth (Sayre, 2008). In tropical agroecological ecosystems, high biological diversity favors ecosystem services such as pollination and biological pest control. However, when this diversity is degraded, the system becomes vulnerable to pests and diseases (Salinas et al., 2024).

Resilience is not only an ecological principle, but also a comprehensive approach to transforming and improving ecosystems and the social organizations that manage them. This concept is key to understanding the limits of agroecosystems, as it assesses their ability to absorb disturbances, adapt, and transform without losing functionality or essential structure. In this sense, resilience and sustainability are complementary concepts that describe the "preferred state" of ecosystems modified by human activity. When resilience declines, the agroecosystem comes dangerously close to its functional limits, requiring the implementation of specific indicators and corrective measures to restore balance (Cañizares et al., 2021; Rocha et al., 2020).

The limits of an agroecosystem result from a combination of ecological, social, and economic factors. These limits define the extent to which an agroecosystem can remain functional, resilient, and sustainable in the face of external pressures.

SUSTAINABILITY AND SUSTAINABILITY: KEY PRACTICES IN AGROECOSYSTEMS

Sustainability and sustainability are key concepts in the development of agricultural systems that seek to balance productivity with the conservation of the natural and social environment. Sustainability, derived from the verb "to sustain," implies the ability of a system, whether natural or human, to remain operational over time without depleting the resources necessary for future generations. This concept emphasizes continuous support within the natural limits of the system. In contrast, sustainability, derived from the verb "to sustain," has a broader scope, focusing on the integration and balance of ecological, social, and economic systems, promoting their permanence and gradual improvement (Yu *et al.*, 2022; Rodríguez-Jiménez *et al.* 2020).

From an ecological point of view, sustainability seeks to conserve natural systems and essential resources such as soil, water, and biodiversity. In the economic sphere, the financial viability of activities is prioritized, while in the social sphere, the participation and inclusion of local communities is encouraged (Balvanera et al., 2017). On the other hand, sustainability not only prevents the degradation of resources, but also incorporates innovative technologies, fosters resilience to climate change, and promotes harmonious development through community cooperation (Rodríguez-Jiménez et al., 2020).

In the context of agroecosystems, sustainability translates into practices such as crop rotation to maintain soil fertility, responsible water management, and biodiversity conservation. For example, a sustainable agroecosystem is characterized by production methods that do not deplete water resources or contribute to soil degradation. These practices allow the system to be productive and stable over time (Vikas & Ranjan, 2024).

Sustainability in agroecosystems adds a more integrative perspective. The aim is not only to prevent degradation, but also to foster resilience to climate change and promote social equity. This includes incorporating innovative technologies and strengthening community participation to achieve harmonious and balanced development. A sustainable agroecosystem, therefore, not only ensures ecological viability, but also addresses economic and social needs, ensuring a holistic approach to agricultural development (Yadav et al., 2021).

Agroecology, as a theoretical and practical framework, integrates these concepts by applying ecological principles to agriculture (Figure 4). It promotes biodiversity, crop rotation, soil health, and natural pest control, while valuing agroforestry and local knowledge (Vikas & Ranjan, 2024). In addition, it focuses on essential ecosystem services, such as maintaining soil fertility, adequate biogeochemical cycles, and efficient nutrient exchange between crops and the soil ecosystem. Through an integrated approach that combines diversified crops and livestock practices, agroecology addresses issues such as food security and the climate crisis, helping to build resilient and sustainable agroecosystems (Yadav et al., 2021).

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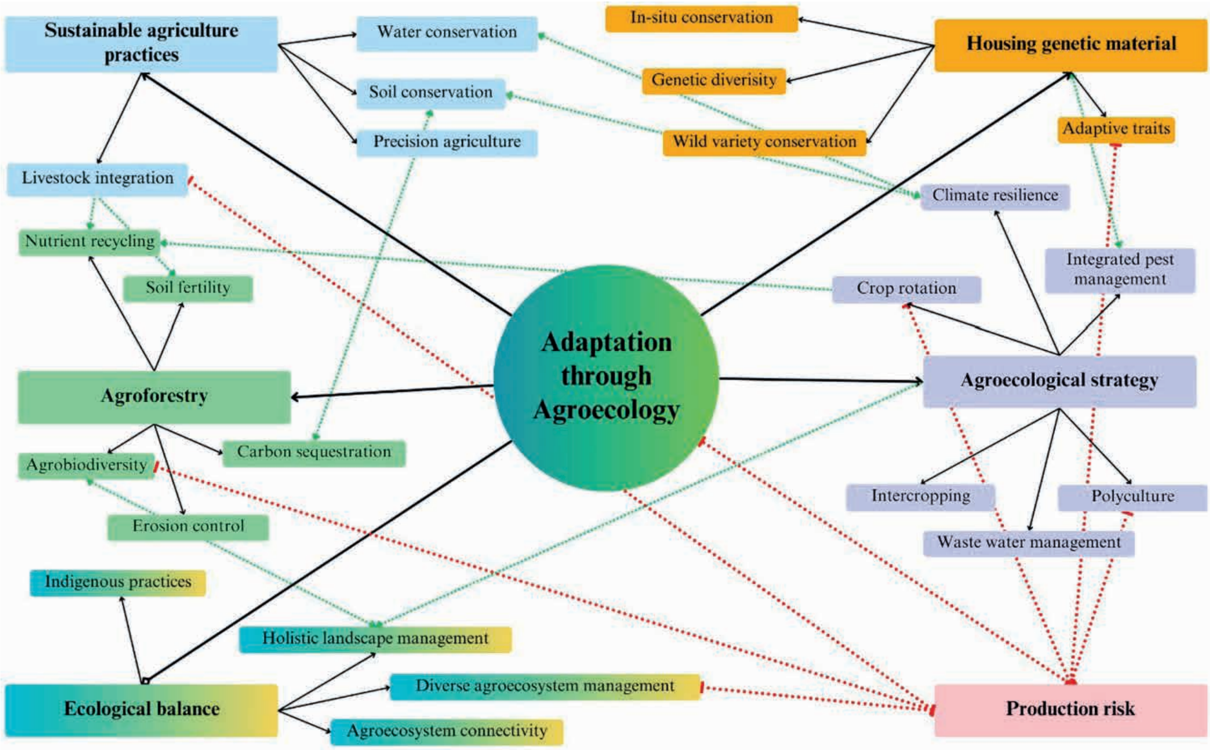

Figure 4. Network of interconnections between various sustainable agriculture practices

CONCLUSIONS

Agroecosystems, in both tropical and temperate regions, are understood as complex systems that integrate biological, cultural, and economic elements within a given space. The interaction between these subsystems determines the agroecosystem's ability to adapt and maintain balance in the face of external pressures, such as climate change and agricultural intensification. While tropical agroecosystems are notable for their biological diversity and the interdependence between their natural and productive elements, temperate agroecosystems face limitations related to seasonality and pressure on biodiversity, which requires the implementation of practices such as crop rotation and soil fertility conservation. The resilience and sustainability of agroecosystems depend on a comprehensive approach that considers the interactions between subsystems and the natural limits of each region. It is crucial that agricultural practices respect these limits and promote the conservation of biodiversity and ecosystem services, such as pollination and biological pest control, to ensure that agroecosystems remain functional and sustainable in the long term. Ultimately, sustainability and resilience in agroecosystems depend not only on productivity, but also on their ability to adapt and remain balanced in the face of global changes and challenges.

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