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Original article

Methodology for the agroecological study of cocoa agroecosystems as a contribution to local development

Metodología para el estudio agroecológico de agroecosistemas cacaoteros como aporte al desarrollo local

Metodologia para o estudo agroecológico de agroecossistemas de cacau como contribuição para o desenvolvimento local

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ABSTRACT

In the rural context, cocoa agroecosystems contribute to local social, economic and environmental development, favoring employment, income generation, organizational processes, access to new knowledge and environmentally friendly management practices, oriented to the conservation of natural resources and the development of rural communities. The objective of this research is to design a methodology for the agroecological study of cocoa agroecosystems from a holistic perspective that contributes to their agroecological management. The research was carried out in farms of the Choco Cotopaxi association, Estero Hondo sector, La Maná canton, in the period 2022-2024. The information was obtained through a rapid rural appraisal that included 32 farms dedicated

to cocoa cultivation. The main result is the development of a methodology that contributes to the determination of agroecological potentialities and the proposal of alternatives for the local context.

Keywords: agroecology; cocoa agroecosystems; local development.

RESUMEN

En el contexto rural, los agroecosistemas cacaoteros realizan aportes al desarrollo local, en lo social, económico y ambiental, favoreciendo el empleo, la generación de ingreso, procesos organizativos, acceso a nuevos conocimientos y prácticas de manejo amigables con el ambiente, orientadas a la conservación de los recursos naturales y el desarrollo de las comunidades campesinas. El objetivo de la presente investigación es diseñar una metodología para el estudio agroecológico de agroecosistema de cacao desde una perspectiva holística que contribuya a la gestión agroecológica de los mismos. La investigación se realizó en fincas de la asociación de Choco Cotopaxi, sector Estero Hondo, cantón La Maná, en el período 2022-2024. La información se obtuvo a través de un diagnóstico rural rápido que incluyó 32 fincas dedicadas al cultivo de cacao. El principal resultado es la obtención de una metodología que contribuye a la determinación de potencialidades agroecológicas y a la propuesta de alternativas para el contexto local.

Palabras clave: agroecología; agroecosistemas cacaoteros; desarrollo local.

RESUMO

No contexto rural, os agroecossistemas de cacau contribuem para o desenvolvimento social, econômico e ambiental local, favorecendo o emprego, a geração de renda, os processos organizacionais, o acesso a novos conhecimentos e as práticas de manejo ambientalmente corretas, orientadas para a conservação dos recursos naturais e o desenvolvimento das comunidades rurais. O objetivo desta pesquisa é elaborar uma metodologia para o estudo agroecológico dos agroecossistemas de cacau a partir de uma perspectiva holística que contribua para seu manejo agroecológico. A pesquisa foi realizada em fazendas da associação Choco Cotopaxi, setor Estero Hondo, cantão La Maná, no período de 2022-2024. As informações foram obtidas por meio de um diagnóstico rural rápido que incluiu 32 fazendas dedicadas ao cultivo de cacau. O principal resultado

é o desenvolvimento de uma metodologia que contribui para a identificação de potenciais agroecológicos e a proposta de alternativas para o contexto local.

Palavras-chave: agroecologia; agroecossistemas de cacau; desenvolvimento local.

INTRODUCTION

The methodology and practice of agroecology come from distinct philosophical roots that differ from those of conventional agricultural science. Agroecology takes into account both the agroecological and socioeconomic systems in which farmers work, emphasizes field experiments with producers (Altieri & Nicholls, 2020), to develop the economic, ecological and social forces that enable sustainable production and prosperous lives for rural and urban populations.

As a dynamic concept that began to be used in the 1920s, agroecology gained importance in the 1980s. It emerges as a new paradigm and science capable of validating and generating knowledge for the evaluation, design and management of sustainable agroecosystems (Sarandón & Flores, 2014), generating ecological principles for the management of food systems (Gliessman et al., 2019).

Agroecology is currently on the agendas of researchers on a global scale. It is conceived as a science, as a system of practices and social movement, as a scientific-empirical approach that envisions the sustainability of agroecosystems (Benítez et al., 2021), and as a framework for the transformation of food systems (Anderson et al., 2021).

When reviewing the research on agroecosystems with *Theobroma cacao L.* (cacao) in Latin America, it is evident the existence of methodological tools interested in the dynamics of these agroecosystems (Nava et al., 2024; Verdezoto Vargas et al., 2023), guaranteeing with their implementation a great flexibility to respond to two of the most important challenges currently faced by researchers:

1. The need to implement a multidimensional assessment of agricultural production systems, with emphasis on the local level (the dimensions refer to the levels of organization "from the family to society, in a country or on a global scale", but also to the economic, social and environmental dimensions that affect the functioning of agroecosystems). The combination of these tools offers a variety of viewpoints on systems, helping to identify synergies and antagonisms between these dimensions.

2. Identification of the key determinants for the design and dissemination of the most interesting systems to face today's global changes and challenges (population growth, erosion, desertification, climate change, etc.). Research for the conception of new systems and their dissemination can be based on the use of these tools to understand the current and future socioeconomic logic of operation and to design new systems with the participation of all the actors involved in the chain.

In this context, the Methodology for the agroecological study of cocoa agroecosystems in La Maná, Cotopaxi, Ecuador is framed; it is based on the dialectical relationship established between the principles of agroecology (HLPE, 2019), the ten elements recognized by the Food and Agriculture Organization of the United Nations, the dimensions that characterize the development and transformation of agroecosystems and the indicators that allow diagnosing their situation and assessing the sustainability of their transformation.

Such relationships will constitute fundamental elements for the agroecological study of cocoa agroecosystems in La Maná, Cotopaxi, which will be present in the design of the methodology that, from an integral, holistic approach, allows understanding the relationships and dependencies between the components or subsystems, detecting their restrictions and, above all, understanding the productive logic, the expectations of the producer and the high agroecological variability. In this sense, the objective of the research was to design a methodology for the agroecological study of cocoa agroecosystem from a holistic perspective that contributes to their agroecological management.

This approach guarantees, on the one hand, to go closer to the understanding of the relevant events that occur in a production process and, on the other hand, to formulate correctly (or as approximately as possible) applicable and reproducible alternatives through an integrated understanding of the dynamics present in cocoa agroecosystems from the economic, social, environmental and political-institutional dimensions, integrated to the variables of the local context, for the revaluation and development of alternatives for rural development.

MATERIALS AND METHODS

The research was conducted in farms of the Choco Cotopaxi association, Estero Hondo sector, in the southern part of the city of La Maná, canton La Maná, province of Cotopaxi; in the period 2022-2024.

The information was obtained through a rapid rural diagnosis that included 32 farms dedicated to cocoa cultivation, of which, based on the productive development and the characteristics of the management applied by the producers, 18 were selected, deepening the diagnosis of the same, for which expert meetings, formal and informal interviews with producers, soil analysis, cluster analysis and Shannon Index were carried out.

RESULTS AND DISCUSSION

The proposed methodology goes from the selection of the agroecosystem to the determination of the potentialities, from the characterization of the system structure and the identification of the fundamental component that determines its functioning and, therefore, of the fundamental interrelationships that are established between the components within the system and with the environment. This analysis leads to consider the cocoa crop as the fundamental component of the cocoa agroforestry system. The stages of the methodology are structured in the order shown in (Figure 1).

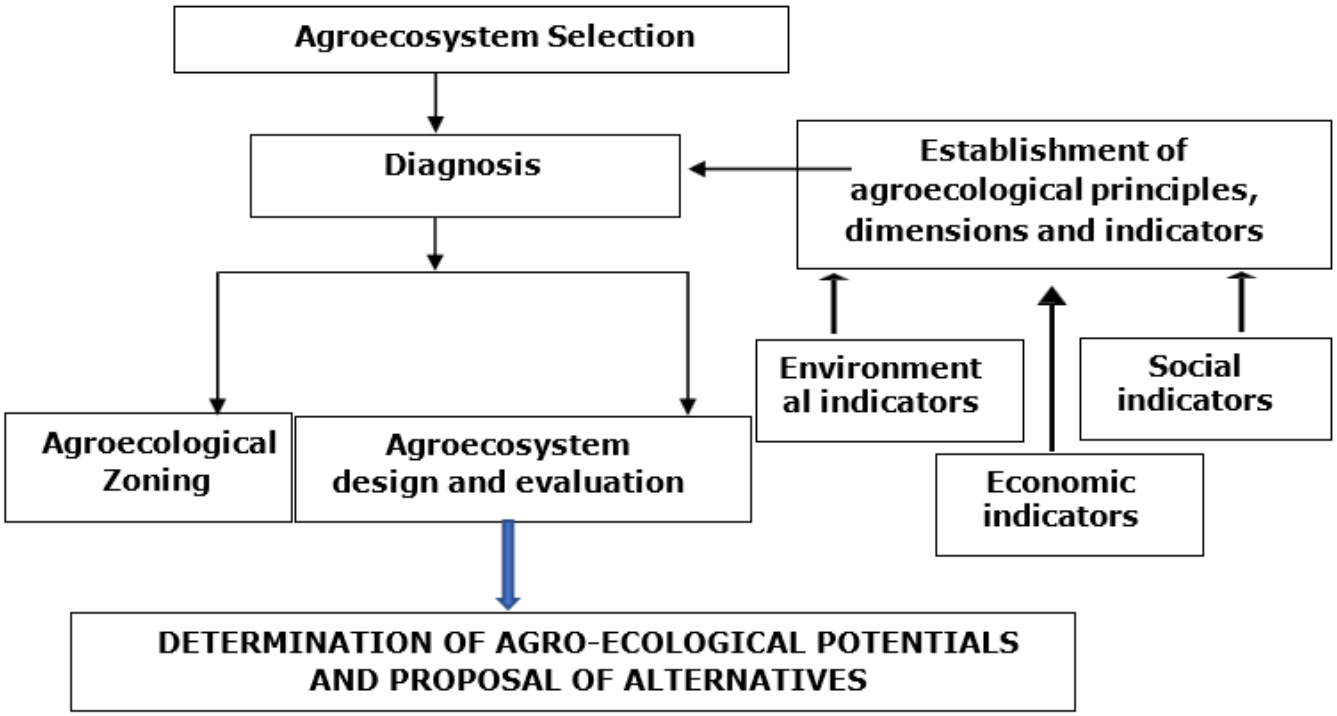

Figure 1. Methodological structure for the agroecological study of cocoa agroecosystems in La Maná, Cotopaxi, Ecuador

Results of the implementation of the methodology

Selection of agroecosystems

Based on the concept that an agroecosystem is the main ecological unit whose function is related to the flow of energy, the recycling of materials through the structural components of the ecosystem and the socioeconomic relations established therein, it constitutes the starting point for agroecological studies. To select the agroecosystems, following the methodology, a previous study of the socioeconomic conditions and productive results, interviews with experienced producers, analysis of the available cartographic material and several expeditions to the area were carried out.

In expert meetings, formal and informal interviews with producers, 32 agroecosystems were identified with evaluation criteria, in the cocoa production developed in the area of La Mana, Cotopaxi. The differentiation between agroecosystems was made taking into account socioeconomic and environmental criteria, resulting in the selection of 18 agroecosystems that represent 73.89 percent of the total area dedicated to this production. These agroecosystems comply with the principle of representativeness of the area, as well as the stability and completeness of the data. The agroecosystems were classified according to the predominant technology into Conventional Agroecosystems, Traditional Agroecosystems and Agroecological Agroecosystems.

Diagnosis

The diagnosis of agricultural systems is a set of procedures to define and analyze these systems, identify their limitations, as well as the causes of these limitations and the potential or possible solutions to improve their performance. The diagnosis serves as a basis for outlining appropriate interventions through design and also for defining research needs. The agroecological diagnosis makes it possible to characterize the current state of agroecological behavior, with the application of the Agroecological Performance Evaluation Tool, in order to strengthen the relationships to be achieved in the system (Figueredo Rodríguez et al., 2025).

The establishment of a set of indicators to diagnose the sustainability criteria of the cocoa systems in the study area was a strategy to be developed by producers and researchers, with the objective of characterizing, evaluating, analyzing and interpreting the functioning of the selected agroecosystems.

Soil analysis was performed at the National Institute of Agricultural Research, Santa Catalina Experimental Station, Soil, Plant and Water Analysis Laboratory, Ecuador.

Effect of climatic variables: Includes the influence of average temperature, average minimum and maximum temperature, average wind speed, average relative humidity and rainfall.

Once the climatic variables of the agroecosystems under study were obtained, their feasibility for fundamental production was evaluated and a grouping was made taking into account these variables; for this purpose, a Cluster and Discriminant analysis was carried out.

In the cluster analysis, there are no defined groups; these are defined by calculating distances or similarities, based on the values of some variables that are considered appropriate for this purpose. In the application of this statistical method for agroecological studies, the variables temperature, relative humidity, wind and rainfall will be used, which will make possible a grouping of agroecosystems according to the climatic similarities between them. Experience in the application to agroecological studies of cocoa-growing areas has allowed to determine the effectiveness of using these methods for the evaluation of samples in groups, allowing greater speed and depth in the analysis.

In discriminant analysis, the groups are known *a priori* (by means of clustering) and explains the belonging of an element to one group or another, on the basis of the values of a group of cases. This technique also makes it possible to identify the variables that determined the grouping.

Agricultural yield (production per unit area) and its components (age of plantation, number of fruits per plant, fruit diameter and fruit length) were evaluated in each agroecosystem.

In agroecological studies it is necessary to calculate the yield, this integral indicator from data collected in the agroecosystem itself and not as a result of studies in plots. This indicator is a measure of site quality and also reflects the management of the systems.

Utilization of the system's secondary productions: Calculation of the level of utilization of secondary productions in the agroecosystem, based on the determination of the production potential of its different components. This indicator provides a measure of the system's utilization of its potential.

Structural composition of the shade: Typification by types of trees that make up the cocoa shade system. This is an indicator of biodiversity, which is not only a reflection of the biological functioning of the system, but also of economic sustainability, since it makes it possible to infer the system's income from other productions.

The Shannon Index relates the proportionality of the number of individuals of each species with respect to the total sample. It is a very useful indicator when it comes to the analysis of complex systems such as cocoa. This value allows relating the richness and abundance of the species of the system with respect to the total of the sample. It is an indicator of biodiversity, which is not only a reflection of the biological functioning of the system, but also of economic sustainability, since it makes it possible to infer the system's income from other productions.

Pest and disease behavior is an indicator that reflects the incidence of pests and diseases in plantations. The presence of pests and diseases is a measure of biodiversity widely used in agroecological studies, reflecting the phytosanitary management of agroecosystems.

Traditional knowledge: It is the reflection of acute observation, experiential learning and the transmission of farmers' knowledge.

Respecting and valuing the knowledge and productive culture of the farmers give richness the research, which leads the results to a conscious intervention of the farmer, the main actor in the process of transforming the sustainability of agroecosystems. Self-assessment through the exchange of experiences and the application of knowledge surveys are techniques that can be used to evaluate the traditional knowledge of farmers engaged in cocoa agroforestry, as a reflection of the cultural context of these systems.

Agroecological zoning

In this study, agroecological zones are considered to be those that have similar combinations of climate, soil and socioeconomic characteristics and the same biophysical potential for production. Agroecological zoning is essential to ensure sustainable development and avoid soil degradation, which directly impacts food security and the local economy (Burgos Carpio et al., 2024).

Zoning makes it possible to group agroecosystems on the basis of an integral analysis, taking into account the selected agroecological indicators. There are several ways to achieve zoning, from the

simplest, such as group analysis, to the use of multivariate statistical methods such as clustering and discriminant analysis, which are very useful techniques for obtaining this result. Geographic information systems have also been used for regional zoning studies.

Depending on the degree of detail with which the work is carried out, agroecological zoning is divided into three categories:

- First approach (at zone level)
- Second approach (at subzone level)
- Third approach (at the area level)

At present, geographic information systems contribute to environmental planning and management strategies. One of its applications is agroecological zoning, a basic tool for adequate and optimal management, where areas with homogeneous characteristics are found that provide valuable information to enhance crop development without damaging natural resources.

The proposed agroecological zoning includes taking into account:

- Agricultural yield and its components
- Climatic variables
- Structural composition of the shadow
- Incidence of pests
- Shannon diversity index
- Traditional knowledge
- Training
- Soil variables

This proposal does not exclude the use of other indicators that would enrich the analysis, but it depends on the possibility of collecting information and using participatory methods. The larger the scale, the better the approach to the reality of cocoa agroforestry systems.

Agroecosystem design and evaluation

In order to carry out this stage, the indicators with the greatest impact on sustainability should be taken into account, selecting the following:

- Agricultural yields
- Incidence of pests
- Shade diversity

Cocoa agroecosystems, being made up of a group of components that converge in time and space, establish a set of interrelationships that characterize each association, resulting in a specific design, determined by the socioeconomic and environmental context in which they are located

Agroecological designs are defined as the agricultural tool or planning instrument to manage sustainable agricultural production with agroecological principles, in the search to reestablish greater environmental integrity in production, promoting a more self-sufficient and sustainable agriculture (Espinosa Alzate & Ríos Osorio, 2016).

The phases for the agroecological conversion of a farm are as follows:

1. Improve input use efficiency through integrated pest management and/or integrated soil fertility management
2. Replace harmful input with beneficial input to the environment (plant or microbial pesticides, biofertilizers, etc.)
3. Redesign the system: diversify with a crop/livestock assemblage, creating synergistic conditions so that the ecosystem can support its own fertility production, natural pest regulation and crop productivity

The design and evaluation will make it possible to compare agroecosystems, determining their behavior and the factors that most affect their functioning. To this end, workshops should be held with producers and statistical analyses should be carried out to clarify the factors that negatively influence their functioning and the conditioning factors that determine this behavior. An analysis of the problems and the causes that give rise to them makes it possible to prioritize the problems and plan a strategy of priorities for solutions.

The diagnoses carried out at an earlier stage for each cocoa agroforestry system allow for the proposal of various agroecological design schemes that promote the introduction of new cropping patterns, which, together with the presence of national cocoa as the main crop on all farms, will have an economic impact that will improve, in the short and medium term, the income of small cocoa

producers, while at the same time making these systems environmentally sustainable (Verdezoto Vargas et al., 2023).

Determination of agroecological potentials and proposal of alternatives

The determination of agroecological potential for cocoa agroforestry systems will be based on a comprehensive analysis of the results of agroecological zoning and the design and evaluation of agroecosystems that reflect their socio-cultural, economic-productive and environmental strengths.

Based on the potentialities, a set of short, medium and long-term measures can be established, aimed at finding real solutions to the problems posed, eradicating the causes that provoke them, without pretending to cover from the beginning all the transformations that need to be made, prioritizing those that contribute most to sustainability and create the basis for effective new solutions.

The stating of solutions leads to the introduction of new elements in the systems, improvement of current components and strengthening of others. This implies a reordering of the energy flow within the agroecosystem and, therefore, its conception as a system within itself would begin to function differently. This should be verified on the basis of a new diagnosis that will confirm the results and the need for further improvements. In the 2030 Agenda for Sustainable Development, we explore the theoretical, epistemological and methodological contributions of agroecology (Druker Ibáñez et al., 2024).

Agroecological designs should be defined from a three-dimensional perspective, that is, looking at the production system, the farm and the environmental setting (market, policies, institutions, technology, technical assistance, among other factors), as a whole and not separated from its reality: systemic approach (Noguera Talavera et al., 2019).

Redesigning the entire system includes the creation of an environmental infrastructure, through diversification at the farm and surrounding landscape level, enhancing ecological interactions that create soil fertility, nutrient recycling and conservation, water storage, pest/disease regulation, pollination and other essential ecosystem services.

Given the unpredictability, increasing frequency and severity of climatic events, it is crucial to determine the adaptive limits of agroecological strategies adopted by farmers in various

environments. In times of drought, many smallholder farmers cope with stress through various crop diversification and soil management strategies. Intercropping systems and agroforestry, complemented by mulching and abundant organic matter applications, can increase water storage capacity, thereby improving crop water use efficiency (Altieri et al., 2025).

The determination of agroecological potential evidences the need to implement a holistic design approach to increase the productivity and stability of the agroecosystem. This would contribute to improve the quality of life of farmers, which is now threatened by climate change, high production costs and subject to price instability in the international market. The analysis reaffirms that agroecology is based on territorial processes that seek to generate solutions to socio-environmental and economic problems from the local level (Gómez Rodríguez & Barbosa Pérez, 2023).

In summary, agroecology as a science, practice and social movement provides the theoretical and methodological foundations for the study of cocoa agroecosystems, based on establishing the dialectical relationship between agroecological principles, elements, dimensions and indicators and providing a systemic, transdisciplinary and multifunctional approach to them in the local context.

The implementation of the methodology for the agroecological study of cocoa agroecosystems in La Maná, Cotopaxi, structured in five stages, allowed, taking into account the management carried out in these agroecosystems, to classify three farm models: agroecological, conventional and traditional, according to the productive development of cocoa cultivation and its contribution to the dynamics of local development.

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Conflict of interest

Authors declare no conflict of interests.

Authors' contribution

Clever Gilberto Castillo De La Guerra and Isidro Rolando Acuña Velázquez determined the theoretical and practical background of the methodology.

Clever Gilberto Castillo De La Guerra and Mariol Morejón García were involved in field data collection, data analysis and interpretation.

All the authors participated in the elaboration of the proposal, designed the research, reviewed the drafting of the manuscript and approved the version finally submitted.