Methodology for Multidimensional, Systemic and Transdisciplinary Analysis in Agricultural Research

Martha Elena Domínguez-Hernández[1,2]***, Rosalba Zepeda-Bautista***[1]

[1]Instituto Politécnico Nacional. Escuela Superior de Ingeniería Mecánica y Eléctrica. Unidad Profesional 'Adolfo López Mateos'. Col. Lindavista, Cd. de México. C. P. 07738. México.

[2]Universidad Nacional Autónoma de México. Facultad de Estudios Superiores Cuautitlán, Departamento de Ciencias Agrícolas, Cuautitlán Izcalli, 54714, Estado de México, México.

*Correspondence: rzepedab@ipn.mx

Received 1 May, 2025; Revised 2 September, 2025; Accepted 3 September, 2025

Available online 3 September, 2025 at www.atlas-tjes.org, doi: 10.22545/2025/00278

Abstract:*Agricultural systems are complex and dynamic, influenced by environmental, socioeconomic, political, and technological factors. Addressing their challenges requires integrative approaches that move beyond traditional disciplinary methods. This paper presents the MSTAAR-methdology (Multidimensional, Systemic, and Transdisciplinary Analysis for Agricultural Research) developed through fieldwork with farmers and institutions in Mexico. MSTAAR offers an 11-phase, iterative framework for diagnosing agroecosystems, co-designing context-sensitive interventions, and evaluating impacts across multiple dimensions. The methodology emphasizes stakeholder participation, systems thinking, and the integration of local and scientific knowledge to foster sustainable agricultural development. A comparative analysis with existing methodologies, such as MESMIS and SALT, highlights MSTAAR's unique capacity to guide intervention design and implementation. Application of the methodology in agroecosystems has shown its effectiveness in generating actionable knowledge, enhancing adaptive capacity, and promoting sustainable practices. MSTAAR provides a replicable, adaptable model for researchers and practitioners committed to transforming agricultural systems in a participatory and contextually grounded manner.*

Keywords:Agroecosystem, Intervention design, Sustainability, Participatory research, Transdisciplinary methodology, Systems approach.

1 Introduction

Agricultural production systems are complex and dynamic socio-ecological entities influenced by multiple, interrelated environmental, economic, social, political, technological, and cultural factors (Gliessman, 2015). These systems face growing socio-environmental and economic challenges including sustainability concerns, climate change, market volatility, resource-use efficiency, and the degradation of natural resources

(Zepeda-Bautista et al., 2021; Suazo-López et al., 2025). Addressing such multifaceted issues requires holistic methodological approaches that move beyond reductionist paradigms and disciplinary boundaries. Moreover, any strategy for improvement must be evaluated and shared with both internal and external stakeholders to transform them into active participants in the development process (López-Ridaura et al., 2002; Reed et al., 2006; Mascarenhas et al., 2010; Measham et al., 2011). These types of systemic approach are enhanced not only by the new mathematical methods, but also by the general philosophical solutions (Mokiy, 2019).

Despite the growing recognition of the need for integrated frameworks, most agricultural research remains disciplinary and segmented, often focusing on isolated technical solutions that overlook the systemic nature of agroecosystems. As Francis et al. (2008) note, while disciplinary approaches have historically enhanced productivity, they frequently neglect the interconnectedness of agroecosystems, thereby undermining long-term sustainability. Among the methodologies with a systemic approach applied in agriculture are First-Order approaches, which investigate "hard" or tangible systems where humans are seen as external regulators, an approach similar to that of unidimensional methodologies (Bawden, 1991; Bawden, 2007). Second-Order methodologies focus on "soft" systems and generally establish links between First and Third-Order approaches. Finally, Third-Order methodologies facilitate the transmission, evaluation, and adoption of knowledge, leading to the re-design of agricultural systems (Bawden, 1991; Bawden & Packham, 1993; Bawden, 2007).

The Hawkesbury Spiral proposed by Bawden (1991), incorporates five learning cycles: Basic Science, Applied Science, Hard Systems Thinking, Soft Systems Thinking, and Critical Systems Thinking. Based on these cycles and the Soft Systems methodology proposed by Checkland and Poulter (2010), it is possible to develop a comprehensive systemic methodological framework.

Several systemic approaches, such as the Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators (MESMIS by its Spanish acronym) developed by López-Ridaura et al. (2000, 2002), and the Sustainability Assessment Adaptive and Low-input Tool (SALT) (Calleros-Islas, 2019), provide tools for evaluating sustainability across multiple dimensions. However, these approaches tend to emphasize diagnosis and monitoring, often lacking explicit guidance for designing and implementing transformative interventions. The Social-Ecological Systems (SES) framework (Ostrom, 2009) offers a structured way to analyze interactions among governance systems, resource users, and ecological components, fostering a deeper understanding of sustainability in complex systems, nevertheless, its practical application in specific agricultural contexts may be constrained by a lack of operational tools. A systemic-transdisciplinary vision requires addressing agroecosystems holistically by considering at least three key dimensions: economic, environmental and social. It also demands participatory research processes that generate solutions reflecting the complexity of the production system's functions and structures, such approaches must account for local constraints and preconditions (Francis et al., 2008; Alrøe and Kristensen, 2002; Eksvärd et al., 2009).

In this context, transdisciplinary methodologies have emerged as essential for generating relevant, actionable knowledge through the co-creation of solutions with stakeholders. These methodologies bring together diverse scientific disciplines and societal actors to tackle the complex challenges confronting agriculture. Transdisciplinary approaches are most effective when they emphasize co-creation, participatory engagement, and the integration of diverse knowledge systems. Foundational works demonstrate how transdisciplinary, evolving and system-oriented approaches can address real-world problems across various domains, such as urbanization (del Cerro, 2019), systems engineering transformation (Ford & Ertas, 2024), research and education (Drugus, 2013; Hernández-Aguilar, 2018; Andrade-Cruz et al., 2025), organic waste reuse (Hernández-Aguilar et al., 2023), and sustainable development (Mokiy & Lukyanova, 2019).

In agriculture, transdisciplinary approaches have proven valuable in fostering collaborative, multidimensional frameworks that address sustainability. These approaches lead to more sustainable, resilient, and context-appropriate agricultural solutions by integrating diverse knowledge systems, co-creating innovations, and promoting stakeholder engagement (Domínguez-Hernández et al., 2022). For instance, collaboration among plant scientists, engineers, computer and social scientists have improved resource efficiency, reduced environmental impact, and promoted the development of innovative technologies (Gilbertson et al., 2020;

Bacheva et al., 2025). To enhance technology adoption among smallholders, co-design processes with farmers, change management workshops, and hybrid knowledge systems have been effective in tailoring solutions to local contexts and increasing innovation uptake (Hazard et al., 2018; Greenhalgh et al., 2019; Sánchez & Cortés, 2019; Restrepo et al., 2020).

Food system transformation and conflict resolution have also benefited from participatory methodologies such as the Community Voice Method, Transformation Labs, participatory filmmaking, and scenario analysis, which foster inclusive engagement, conflict mediation, and actionable outcomes (Calla et al., 2022; Gasparatos et al., 2023). Likewise, the digitalization of agriculture has advanced through stakeholder integration, risk assessments, and the co-development of responsible innovation guidelines, helping identify potential risks and establish socially robust frameworks (Zscheischler et al., 2022). In agroecology and biodiversity, mutual learning between researchers and farmers, alongside the adaptation of scientific goals to farmers' needs, has improved sustainability and enabled the implementation of context-specific practices (Fernández et al., 2020). Finally, the evaluation of new technologies and decision-making processes have been enriched by multi-stakeholder assessments, fuzzy set methods, and participatory weighting of factors, resulting in more comprehensive evaluations that integrate both social and environmental dimensions (Siebrecht, 2020; Liang et al., 2023).

Transdisciplinary, multidimensional, and systems thinking-oriented approaches are indispensable for addressing the complex and interconnected challenges of contemporary agriculture. In alignment with this perspective, the present study proposes a methodology tailored specifically to agricultural research contexts. This paper introduces the MSTAAR methodology (Multidimensional, Systemic and Transdisciplinary Analysis for Agricultural Research or AMSTIA by its Spanish acronym), developed from extensive fieldwork with farmers and institutions in Mexico. MSTAAR offers a structured, flexible and iterative framework that enables researchers and stakeholders to jointly assess agroecosystems, design improvement strategies, and evaluate the outcomes of interventions across multiple dimensions. The methodology integrates principles from systems thinking, soft systems methodology, sustainability assessment, and participatory research to facilitate context-sensitive innovation and learning. Its application not only generates scientific knowledge but also strengthens local capacities for sustainable agricultural development.

2 Methodology

2.1 Identification of the Problem and Methodological Gap

One of the key limitations in agricultural research in Mexico is the low availability of comprehensive methodologies to analyze and evaluate production systems or assess the impact of interventions aimed at improving them across multiple sustainability dimensions. To better understand the current methodological landscape, a systematic literature review was conducted using the Web of Science® database. The search focused on peer-reviewed scientific articles in English or Spanish, published in indexed international journals between 1900 and 2025. Keywords used included: Sustainability, assessment, analysis, framework, methodology, indicators, sustainability dimension, multidimensional approach, agriculture, and agroecosystem.

This search yielded 220 results, of which titles and abstracts were reviewed to exclude studies that did not address at least two dimensions of sustainability. A total of 110 articles were selected for full content analysis to determine whether they proposed or applied a specific methodology. This qualitative review identified only two methodologies developed in the Mexican context, the MESMIS framework (Masera et al., 1999; López-Ridaura et al., 2000, 2002) and the SALT Tool (Calleros-Islas, 2019).

2.2 Comparative Analysis of Methodologies

To highlight the uniqueness of MSTAAR, a comparative analysis was conducted with both MESMIS (Masera et al., 1999; López-Ridaura et al., 2000, 2002) and SALT (Calleros-Islas, 2019). Table 1 summarize differences across various criteria: objectives, evaluated dimensions, type of system analyzed, phases, required data, indicator selection, evaluation approach, and data types. MESMIS is a systemic and interdisciplinary

Table 1: Comparison of the MESMIS, SALT, and MSTAAR Methodologies.

Characteristic	**MESMIS**	**SALT**	**MSTAAR**
Evaluated Dimensions	Economic, environmental, and social.	Social, institutional, economic, and environmental.	Economic, environmental, and social.
Objective	Evaluate the sustainability of natural resource management systems at a local scale.	Evaluate sustainability in local context.	Improve a production system using a multidimensional, systemic, and transdisciplinary approach.
Study Focus	Management systems.	Local production systems.	Production systems, agroecosystems, and management systems.
Phases	1. Definition of the study object. 2. Identification of strengths and weaknesses. 3. Selection of strategic indicators. 4. Measurement and monitoring. 5. Integration and presentation of results. 6. Conclusions and recommendations.	1. Identification of context-specific, rapid-assessment, flexible indicators. 2. Qualitative and quantitative indicator measurement. 3. Presentation of results using AMOEBA graph.	1. Definition of the study object. 2. Diagnosis of current agroecosystem. 3. Identification of influencing factors. 4. Design of interventions. 5. Design of evaluation instruments. 6. Training for demonstration units and data collection. 7. Implementation of interventions. 8. Monitoring of interventions. 9. Experimental data and record collection. 10. Data analysis. 11. Integration and presentation of results.
Required data	Surveys, measurements.	Averages from alternative/conventional systems (data collection process not specified).	Statistical and geographical data, surveys, direct measurements, and experimental data.
Evaluation Approach	Comparison between conventional and alternative system.	Comparison between conventional and alternative system.	Comparison among current, reference and improved systems.
Indicators	Not predefined.	Flexible set of 18 indicators.	Flexible selection of sustainability indicators for each dimension evaluated.
Indicator Measurement	Determined by the researcher.	Surveys, field observation, metadata.	Survey, lab analyses, direct measurements, estimates, calculations.
Indicator weig hting	Not specified.	Based on farmer perceptions; normalized on a scale from 0 to 100.	Based on reference value; normalized on a scale from 0 to 10.
Data type	Qualitative and quantitative.	Qualitative.	Qualitative and quantitative.

MSTAAR = Methodology for Multidimensional, Systemic and Transdisciplinary Analysis in Agricultural Research; MESMIS = Framework for the Assessment of Natural Resource Management Systems Incorporating Sustainability Indicators (Masera et al., 1999; López-Ridaura et al., 2000, 2002); SALT = Adaptive and Low-input Tool (Calleros-Islas, 2019).

framework based on the qualitative characterization of natural resource management systems. It identifies system components such as inputs, outputs, and socioeconomic characteristics. While useful for evaluating sustainability, the MESMIS framework lacks specific guidance on result comparison methods and the selection of indicator values for graphical representation (e.g., AMOEBA graphs). Moreover, it does not explicitly include intervention design or participatory co-construction as part of the research process. SALT builds upon MESMIS, adapting it for use in contexts with limited human, financial, and technical resources. It introduces easily measurable indicators and integrates the institutional dimension into the assessment. SALT also simplifies data collection, requiring fewer expert inputs. However, like MESMIS, it focuses primarily on diagnosis and evaluation, without addressing the design and implementation of improvement interventions. The comparative application of MESMIS and SALT in agricultural research highlighted the need for a methodology that combines systemic, multidimensional, and transdisciplinary principles, and explicitly incorporates the co-design and evaluation of interventions with the active participation of stakeholders.

Additionally, to illustrate the transdisciplinary relevance, MSTAAR was compared with other transdisciplinary frameworks outside of agriculture, such as the researcher training model proposed by Hernández-Aguilar (2018) and the EMMY model developed by Drugus (2013). The three approaches share a foundational commitment to addressing real-world, complex problems through the integration of multiple disciplines and stakeholder participation. However, their scopes and applications differ significantly. While the MSTAAR methodology is specifically designed for evaluating and transforming agricultural production systems, the Hernández-Aguilar (2018) model is oriented toward training researchers in transdisciplinary practice, and the EMMY model focuses on philosophical and educational frameworks for addressing epistemological complexity (Drugus, 2013).

In terms of structure, MSTAAR consists of 11 well-defined phases, from problem definition to participatory evaluation and feedback. In contrast, Hernández-Aguilar (2018) proposes a four-stage process (contextualization, diagnosis, intervention, and impact evaluation), while the EMMY model is organized around three levels: ontological (reality), epistemological (knowledge), and logical (structure) (Drugus, 2013). All three methodologies emphasize actor involvement, but MSTAAR demonstrates a higher degree of integration of stakeholders such as farmers, technicians, and institutions throughout the research cycle. Disciplinary integration also varies: MSTAAR draws from agronomy, systems engineering, ecology, economics, and social sciences; Hernández-Aguilar's model focuses more on educational and methodological sciences; while EMMY incorporates philosophy, complexity theory, and pedagogical logic. A key shared feature is their adaptive and iterative nature. Each methodology evolves according to the problem context and the dynamics of knowledge production. However, MSTAAR is distinguished by its direct application in agricultural research and its capacity to produce empirical, actionable, and locally validated knowledge. It has been successfully applied in multiple agricultural projects in Mexico, with documented results in productivity, sustainability, and actor empowerment.

2.3 Development of the MSTAAR Methodology

In response to the identified gap, the MSTAAR methodology (or AMSTIA for its Spanish acronym) was developed. This methodology is grounded in the Hawkesbury Spiral (Bawden, 1991), which integrates multiple learning cycles from Basic Sciences to Critical Systems Thinking. These cycles form the epistemological foundation for understanding and transforming complex agricultural systems through iterative, participatory processes. Likewise, MSTAAR uses the systemic-transdisciplinary approach to generate models of spatial, temporal and informational units, which allow for deeper studies of non-biological, biological and social objects (Mokiy, 2019), and the transdisciplinary model of the Mexican agricultural process proposed by Sánchez & Cortés (2019).

MSTAAR expands upon existing frameworks, providing a structured process composed of eleven sequential phases. These include problem definition, diagnosis, identification of influencing factors, intervention design, field implementation, participatory monitoring, data collection, and comparative evaluation of the current, reference, and improved systems. This structure enables both quantitative and qualitative data collection, temporal evaluation, and comparative analysis.

MSTAAR emphasizes co-creation and transdisciplinary collaboration among researchers, technicians, farmers, and institutions. It integrates disciplinary knowledge from agronomy, systems engineering, ecology, economics, and the social sciences. Furthermore, it allows for the development of tailored interventions and the generation of local and scientific knowledge, aligning with the principles of socially robust, actionable research.

3 Results and Discussion

3.1 Transdisciplinary Process within the MSTAAR Methodology

The Multidimensional, Systemic and Transdisciplinary Analysis for Agricultural Research (MSTAAR) methodology was designed to address the complexity of agroecosystems through a transdisciplinary approach. This approach is operationalized through the integration of researchers from multiple disciplines, including agronomy, systems engineering, edaphology, chemistry, social sciences, statistics, and economics, and the active involvement of farmers, technicians, and local institutional actors throughout the research process.

MSTAAR involves several stages that promote stakeholder collaboration: a contextual diagnosis based on local knowledge and scientific literature; participatory identification of constraints and opportunities within the agroecosystem; co-design of experimental interventions; collective training and monitoring; and shared evaluation and dissemination of results. At each stage, actors evolve from passive informants to active co-researchers, reflecting the evolving researcher role described by Alrøe & Kristensen (2002) and Hernández-Aguilar (2018).

As emphasized by Drugus (2013), a key feature of transdisciplinary methods is their ability to transcend rigid disciplinary categories and address real-world problems using knowledge from multiple levels of reality. MSTAAR embodies this principle by adapting to the specific social, environmental, economic, and cultural conditions of the territories where it is applied. Furthermore, its iterative nature enables feedback loops that strengthen decision-making, build trust among actors, and allow for continued improvement over time.

These features align with the criteria for transdisciplinary methodologies established in the literature (Wickson et al., 2006), particularly: Focusing on socially relevant problems; transcending disciplinary boundaries; and developing evolving methodologies. MSTAAR operationalizes these principles by placing the co-construction of knowledge and the transformation of agroecosystems at the core of its application.

Additionally, Vilsmaier et al. (2017) emphasize that transdisciplinary research emerges in an "in-between space", shaped by cultural differences between various knowledge and actions domains. MSTAAR embraces these differences as a source of mutual learning and co-creation, by fostering a hybrid cultural space the proposed methodology supports the production of situated, transformative, and socially relevant knowledge.

3.2 The Multidimensional, Systemic and Transdisciplinary Analysis for Agricultural Research (MSTAAR) Methodology

The Multidimensional, Systemic and Transdisciplinary Analysis in Agricultural Research (MSTAAR) consists of 11 phases (Figure 1), beginning with the definition of the object of study and culminating in the integration and presentation of results to both farmers and the scientific community, incorporating feedback at each stage. It is important to highlight that while that phases are grounded in the Mexican context, then can be adapted to other countries.

3.2.1 Phase 1: Definition of the Object of Study

This phase begins with the observation of the environment, understood as the activity of detecting, identifying, and assimilating relevant information. It includes the geographic and temporal contextualization of the research. Based on this observation, the problem or problems to be addressed are defined in relation to the needs of the population, with particular attention to local farmers.

It is advisable to define the research problem through a systematic analysis of the available information at the time the research is initiated. This can be done through two complementary strategies:

1. Review of Scientific and Popular Literature, including statistical databases and intellectual property registries.

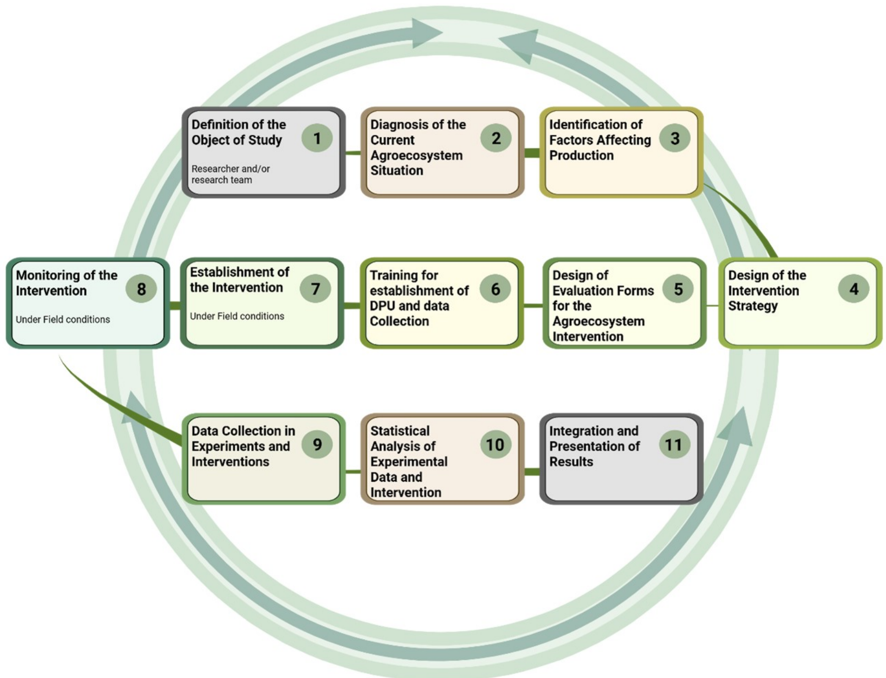

Figure 1: Methodology for multidimensional, systemic and transdisciplinary analysis in agricultural research (MSTAAR).

2. Fieldwork, through consultations with theoretical and practical experts such as local farmers, agricultural engineers, researchers, and representatives from government or private institutions linked to agricultural production. In this context, Sánchez & Cortés (2019) propose a transdisciplinary model of the Mexican agricultural process that links three sectors and multiple fields of knowledge. First, the field of empirical knowledge of farmers; second, the field of scientific knowledge of academics; and third, that of technicians and technologists, respecting the sociocultural practices and the sociohistorical, political, cultural, ecological, and environmental context of each sector.

A tentative research title (15 to 20 words, including connectors) should be formulated, reflecting the research context. It must be clear and precise, guiding the formulation of the general objective, methodology, and expected outcomes. Once the title is defined, three to six keywords should be selected to guide the literature search. The search should progress from general to specific, combining keywords systematically.

Suggested databases for literature review include Scopus, Science Direct, Web of Science, Emerald, SciELO, and Redalyc. Statistical information on agricultural food production can be found in the databases of the Food and Agriculture Organization of the United Nations (FAO via FAOSTAT), and the United States Department of Agriculture (USDA). In Mexico, relevant data can be accessed through the Secretariat of Agriculture and Rural Development (SADER), the Agri-Food and Fisheries Information Service (SIAP), the National Institute of Statistics and Geography (INEGI), the National Population Council (CONAPO), the National Commission for the Knowledge and Use of Biodiversity (CONABIO), and the National Service for Seed Inspection and Certification (SNICS). These acronyms correspond to their original Spanish-language titles.

It is also recommended to consult intellectual property databases to identifying existing technologies, assess their applicability into the intervention, or to explore opportunities for protection of innovations that benefit local communities. Key sources include the World Intellectual Property Organization (WIPO) and the Mexican Institute of Industrial Property (IMPI). Farmers should be informed about rights related to trademarks, patents, and designations of origin to enhance the value of their products and practices.

Various types of publications may be consulted, including scientific and popular articles, books, brochures, manuals, refereed conference proceedings, and in some cases theses in Spanish, English, and other languages. The literature review should cover at least the past 10 years divided into five-year periods, while including foundational works regardless of publication date. Empirical knowledge provided by local inhabitants, especially farmers, is also essential, this can be obtained through surveys or participatory rural appraisal techniques. Validated information, both scientific and empirical, should support the definition of the research problem and its justification.

Once the conceptual and contextual foundations are established and the problem defined, the physical site for the research is selected. According to the MSTAAR methodology, the following types of information are necessary to define the object of study:

1. *Geographic Location:* Coordinates obtained via INEGI databases (for localities, municipalities, states, or regions) or GPS (for individual production units).
2. *Hydrology and Topography:* Slope, water bodies, and terrain features from INEGI or CONABIO databases, or collected through direct observation and local knowledge.
3. *Climatic Conditions:* Climate data from the nearest meteorological station or on-site measurements (portable weather station, thermometers or rain gauge), including average, maximum, and minimum temperature, and precipitation distribution.
4. *Soil Properties:* Physical and chemical soil data from INEGI or CONABIO databases, or through laboratory analysis of samples collected using probabilistic or non-probabilistic sampling methods at the study site.
5. *Demographic Information:* Population size, age, gender distribution, education level, economic activity, and marginalization indices, based on INEGI and CONAPO data.
6. *Economic Activities:* economic profiles of the area, available from INEGI.
7. Infrastructure and Access: Communication routes from INEGI databases or field verification.
8. *Government Programs:* Agricultural and forestry initiatives promoted by SADER, Fundación Produce, and other federal or state entities such as Secretariat of Economy, Secretariat of Science, Humanities, and Technology and Innovation (SECIHTI for it Spanish acronym).
9. *Agricultural and Forestry Production Statistics:* Data on yield, prices, planted and harvested area, inputs, and production value from SIAP, SADER, and INEGI.
10. *Cultural Context:* Local knowledge, customs, and traditions, accessible through government sources or direct community engagement.

This information must be analyzed holistically to justify the research. The following questions should guide the process: *Why is this object of study important? And who will benefit from the research?*

From this foundation, the system under study can be defined, including its components, functions, boundaries, and internal/external influencing factors. As Meadows (2008) defines, a system is a "set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors or functions". Understanding this structure supports the characterization of local populations and their interactions.

This phase also lays on the groundwork for designing future interventions by addressing two key questions:

- *How will technology or knowledge be transferred?*
- *How will it be adopted by the population?*

The Role of the Researcher and Research Team

The researcher or research team plays a central role in Phase 1. Jenkins (as cited in Gigch, 2006) emphasizes that problem analysis is best approached collectively, requiring interdisciplinary collaboration tailored to the complexity of the issue. Conversely, Alrøe & Kristensen (2002) highlight the importance of the researcher's worldview, values, and method of observation in shaping the production of knowledge.

In the MSTAAR approach, researchers initially serve as observers. However, as research advances, they transition into active participants, becoming part of the studied agroecosystem. This evolution is influenced by the context, the nature of the problem, and the epistemological stance of the team. For researchers in training, Hernández-Aguilar (2018) describes them as agents of change, individuals who investigate themselves and their environment to propose transformative solutions. Thus, the act of research is both introspective and contextual, aimed at catalyzing meaningful change in agricultural systems.

3.2.2 Phase 2. Diagnosis of the Current Situation of the Agroecosystem

This phase begins with a thorough analysis of contextual information to define the key indicators or study variables to be evaluated. The process involves identifying the target population, designing and applying the survey, generating a database, analyzing the information statistically, and establishing a baseline for future evaluation.

Available indicators can be found in scientific articles (Brunett-Pérez, González-Esquivel & García-Hernández, 2005; Domínguez-Hernández, 2018; Calleros-Islas 2019; Schindler et al., 2016; Schindler, Graef & König, 2015; Koppelmäki et al., 2021; Domínguez-Hernández et al., 2025), as well as in publications such as the FAO's SAFA Sustainability Assessment Guidelines for Food and Agriculture Systems (FAO, 2013), and within the MESMIS Framework (Astier et al., 2008) or IDEA (Zahmn et al., 2008). It is important to note that the list of indicators is flexible and can be adapted by each researcher to fit the specific context of their system.

Selection of the Target Population and Sample Size

The study population includes farmers involved in the agricultural activity under investigation, defined geographically by the physical limits of the study area. Information is obtained from official sources (e.g., SADER) or directly from local farmers.

The sample size is calculated based on:

1. **Confidence level** (typically between 90-99%), indicating how reliably results can be generalized.
2. **Margin of error** (usually 1-10%), indicating acceptable deviation from population values.
3. **Population variability** is assumed as p=q=0.05 when no prior information is available.

The common equations for sample size estimation are: n $= (z^2\sigma^2 N)/((N-1)E^2 + z^2\sigma^2)$; where: n is the sample size, z is the normal score, σ is the standard deviation, N is the population size and E is the estimation error (Badii et al., 2008); and the equations proposed by Malhotra (2004), for known and unknown populations, respectively: $n = (z^2pqN)/(NE^2 + z^2pq)$and $n = (z^2pq)/E^2$; where: n is the sample size, z is the normal score, p is the positive variability, q is the negative variability and E is the estimation error.

Survey Design

The survey serves both as a data collection tool and a research method. It should be aligned with the study objectives and tailored to the target population. The instrument may include questionnaires, interviews, and opinion scales, and must support measurement of the selected variables or indicators (Alaminos & Castejón, 2006). Field-based variables such as soil and climate conditions from Phase 1 should also be included.

A semi-structured survey typically includes the following sections:

1. **Farmer profile:** Demographics, education, experience, record-keeping practices.
2. **Socioeconomic Data:** Households dependents, labor force, income and expenses, extension services received.
3. **Production Unit Characteristics:** Location (GPS), land tenure, soil type and analysis, crop history from 5 years, climate records.
4. **Production practices:** Activities related to land preparation, planting, irrigation, pest and disease control, harvesting, and post-harvest management, with associated costs, inputs and frequency.
5. **Marketing:** Commercialization channels, buyers, quantities sold, pricing, and market logistics.
6. **Infrastructure and Assets:** Machinery, equipment, storage and processing facilities, and digital tools for management.
7. **Environmental Practices:** Water use efficiency, soil conservation, organic fertilizer use, pest control methods, waste management.

Once drafted, the survey should undergo expert validation and pilot testing with a small group of farmers to ensure clarity, completeness, and usability.

Application of the Survey (Probability and non-probability sampling)

Surveys are applied to a representative sample of the study population. Sampling is guided by inclusion and exclusion criteria and can be probabilistic or non-probabilistic:

Probabilistic Sampling Methods (Badii et al., 2004, 2011):

1. **Simple random:** Used when the population is homogeneous.
2. **Systematic random:** Applied when the population is ordered.
3. **Stratified random:** Used when the population can be divided or grouped into distinct strata.
4. **Cluster Sampling:** Applied when population groups (clusters) can be sampled instead of individuals.

Non-probabilistic Sampling Methods (Otzen & Manterola, 2017):

1. **Purposive Sampling:** Researcher select cases based on specific criteria.
2. **Convenience Sampling:** Participants are selected based on availability and willingness.
3. **Consecutive (Incidental) Sampling:** Participants are included until the sample size is reached.

Surveys should preferably be administered at the end of the agricultural cycle to capture recent, relevant information. They can be conducted: On-site (at production units), in farmer meetings, at home, electronically or using a mixed approach.

Prior to survey deployment, interviewers must be trained by experts familiar with the agroecosystem dynamics to ensure accurate and consistent data collection. Georeferencing of questionnaires is strongly recommended for future geospatial analyses.

Data processing

Data processing involves capturing and organizing responses into a structured database:

1. **Database Construction:** Use specialized software (Access®, SQL® or Excel®). Each field must be clearly labeled with its variable name, value type, and measurement scale. Qualitative variables should be coded for efficient analysis.
2. **Data Entry:** Survey responses are inputted into the database, with each record assigned a unique ID for traceability and verification.

Statistical Analysis of the Information Collected

The database is analyzed using descriptive and multivariate statistical techniques:

1. **Variable Reduction:** Principal Component Analysis (PCA) is used to identify key variables and simplify complexity (Sokal, 1977).
2. **Typology Development:** Cluster Analysis groups observations into similar categories or profiles (Berdegué et al., 1990; Köbrich et al., 2003; Han et al., 2012).
3. **Cluster Characterization:** Each cluster is described using both quantitative and qualitative variables. Quantitative variables are analyzed using measures of central tendency (mean, mode, and median) and dispersion (standard deviation and variance). For qualitative variables, proportions or percentages are calculated to capture the distribution of attributes within each cluster.

This analysis reveals underlying patterns and identifies key factors influencing production, helping target interventions more effectively.

Baseline Establishment

To establish the baseline of the study system, it is essential to define reference values that represent the system's current state. These reference values can be obtained directly from the study system, from data sources, or from scientific literature. For each indicator, a reference value that accurately reflects the characteristics of the system will be selected.

Each reference value is assigned a weight of 5 on a scale from 0 to 10 to standardize the assessment and facilitate the visualization of system performance. The weighted values of all indicators will be compiled into a table and visually represented using a radial chart or line graph. This graphical representation supports easier interpretation of the data.

The results will be analyzed to identify trends and relationships among the indicators, and to adjust or define new reference values that are better aligned with the current context of the system. Indicators performing above the baseline are interpreted as having a positive trend, while those below the baseline indicate negative performance.

The baseline provides a snapshot of the initial conditions of the system across multiple dimensions and serves as a benchmark to evaluate future interventions and supports evidence-based decision-making for improving agroecosystem resilience and performance.

3.2.3 Phase 3. Identification of Factors Affecting Production

Building on the information gathered and analyzed during the diagnosis and baseline development (Phase 2), this phase focuses on identifying the key positive and negative critical points across each component of the agroecosystem. This step is essential to determining which elements of the system are functioning effectively and which require improvement, prior to implementing intervention strategies. Positive aspects should be preserved and enhanced where possible, while negative aspects should be addressed and mitigated to prevent their recurrence.

It is recommended to assess at least the following categories of factors: Environmental, social and cultural, economic, politic, technological, and agronomic management (Table 2). For each category, the following guiding questions should be considered:

- How does this factor affect the agroecosystem under study?
- Is it feasible to modify?
- If so, how, when, and where should modifications be applied

Table 2 serves as a practical tool for researchers or research teams to identify, prioritize, and manage the factors to be addressed during the design, evaluation, and implementation of the intervention. The selection of these factors should be based on scientific evidence and supported by appropriate methodologies, methods, techniques, or tools from both basic and applied sciences. This enables the development of a comprehensive framework that integrates system diagnosis, solution design, evaluation, and the implementation of strategies to improve agroecosystem performance.

Moreover, the integration of an inter and multidisciplinary team, including specialists from all relevant fields, is strongly encouraged to ensure a comprehensive and reliable assessment of the system. The validation of both the diagnosis and the proposed strategies through a plenary meeting with agricultural producers and other key stakeholders is also recommended. This participatory process fosters consensus-building and help align efforts toward the shared goal of collaborative and sustainable agroecosystem improvement.

Table 2: Guide to identify positive and negative factors and critical points affecting production in the study agroecosystem.

Factor	Positive Critical Point	Negative Critical Point	How does it affect the system?	Is it feasible to modify?
Environmental				
Social/Cultural				
Economic				
Political				
Technological				
Agronomic management				

This tool also helps validate the accuracy of the diagnosis and the relevance of the intervention strategies, while encouraging active participation from all key stakeholders, including farmers, subject-matter experts, and representatives from public and private institutions.

Factor Selection and Levels to Evaluate in the Intervention

When selecting factors for experimental study, priority should be given to those that are both modifiable and measurable across a range of levels. This enables the application of contour plots and response surface methodologies to gain deeper insights into system behavior and interactions. It is advisable to select evenly spaced levels within a meaningful range to enhance the ability to detect differences in performance outcomes.

The selection of factors and their respective levels must be supported by a solid scientific and technological foundation. This may be established through literature reviews, consultations of intellectual property databases, results from previous experiments conducted under similar conditions, and critically assessed empirical knowledge.

Additionally, the selection process should take into account the spatial, temporal, human, economic, and environmental resources available for the intervention.

For the design and evaluation of the intervention, factorial experiments are recommended, as they are more efficient than one-factor-at-a-time (OFAT) approaches. Factorial designs allow for the simultaneous evaluation of multiple factors and their interactions, leading to optimization of the intervention with fewer resources. These experiments facilitate the generation of contour plots and response surface graphs, which can help identify the optimal levels of each factor. The data obtained includes both main effects and interactions, supporting more informed decision-making and more efficient use of resources (Montgomery, 2016).

3.2.4 Phase 4. Design of the Intervention Strategy

Presentation of Diagnosis Results and Factor Selection

Based on the results from Phase 3, a meeting should be convened with the key stakeholders of the agroecosystem. This includes the lead researchers, academic collaborators, representatives from educational institutions, local authorities, participating farmers, and other agricultural producers from the study area. During this meeting, the following elements will be presented: the comprehensive diagnosis of the agricultural production system, the baseline, identified positive and negative critical points, and the modifiable factors that could inform the intervention strategy.

Following the presentation, stakeholders will vote to either approve or reject the results, by consensus or by majority vote. If the results are not approved, the process returns to the diagnostic phase. If approved, the planning and execution of workgroups will proceed under the coordination of the lead researcher(s) to select the specific factors that will be included in the intervention design. This step ensures a systemic and transdisciplinary research approach.

Experimental Design of the Intervention

Before designing the intervention, all participants should clearly understand the following: What exactly will be studied? How will data be collected?, and What is the expected method of analysis, both qualitatively and statistically. Once the intervention has been defined and agreed upon, the design should follow standard experimental procedures (Montgomery, 2016) including:

- Selection of factors and levels.
- Identification of response variable(s).
- Choice the experimental design.
- Establishment, management, and documentation of the experiment.
- Statistical data analysis.
- Drawing conclusions and making recommendations.

The selection of factors and their respective levels should be grounded in scientific and technological literature, field-based diagnostic results, researcher's scientific and practical expertise, and farmers' local knowledge of the agroecosystem. In other words, this step synthesizes Phases 1 through 3. Once the factors and levels are established, treatments are defined, each representing a specific combination of experimental conditions to be applied to an experimental unit (EU). An EU may refer to an object, plant, seed, grain, animal, or a physical plot where the treatment is implemented. Variables determined by the research team will be recorded and analyzed within each EU.

Types of experiments include:

1. **Simple comparative experiments,** where two treatments are compared.
2. **Single-factor experiments,** involving one factor with two or more levels (t treatments in total)
3. **Factorial experiments** involving two or more factors (e.g., A and B), each with multiple levels (a x b = t treatments in total).

To answer key design questions, such as which treatments to evaluate, how many, where, when, and how, the following aspects must be considered:

- The research context and objectives.
- Availability of natural, human, financial, and infrastructural resources.
- Theoretical and methodological framework guiding the intervention.

Based on these considerations, the research team and stakeholders will jointly decide on the number of treatments to evaluate. Next, response variables must be selected, ensuring they provide valid and reliable data relevant to the research question. The variable type, measurement scale, and corresponding statistical methods (Walpole et al., 1999) should also be defined.

The experimental design and field layout of EUs are then finalized. An experimental design is a structured plan in which one or more factors, with different levels, are randomly assigned and controlled across EUs. This structure enhances the validity of results and optimizes resource use by minimizing error. The precision of the design depends on the number of blocking factors, ranging from none (in a completely randomized design) to three or more (in a mutually orthogonal Latin square design).

Blocking factors are external variables that may affect the response but are not of primary interest, such as soil fertility, slope, water availability, or nearby vegetation. These must be controlled to avoid confounding effects. Blocking involves grouping EUs that are similar in one or more of these characteristics. Common designs include Randomized block design (one blocking factor), Single-factor experiments (two blocking factors), and Factorial experiments (three blocking factors) (Martínez, 1996; Montgomery, 2016).

Once the design is selected, treatments are randomized across blocks and within each block. Then EUs are numbered and described, followed by the creation of a detailed layout or field map showing their spatial distribution, based on soil and topographic characteristics. This visual guide facilitates the experiment's setup, management, and monitoring.

Field Work Planning and Workbook Design

As part of the experimental planning, a detailed workbook must be prepared. This workbook should include: a description of each test to be conducted; the sequence in which the experimental activities will take place; the procedures for measuring results and collecting data; a list of project team members and their assigned responsibilities; and step-by-step instructions for carrying out each test. It should also specify the dates for data collection, the materials and measurement instruments to be used, and the contingency actions to be taken in case of unforeseen events (Gutiérrez & De la Vara, 2012).

The workbook should include:

1. **Cover page:** Includes project title, logos, and names and roles of participating stakeholders.
2. **Intervention design:** List selected factors, levels, treatments, experimental design, randomization details, and input preparation (e,g., soil, seed, fertilizers, agrochemicals).
3. **Field layout:** A detailed sketch of EU distribution with reference points to ensure replicability.
4. **Agronomic management log:** Records all production activities (land preparation, planting, cultivation, pest/disease/weed control, harvest, etc.) with details on where, when, how, and with what each task was performed.
5. **Data recording sheet:** A structured format (Table 3) to record all variables in accordance with the experimental design.
6. **Statistical analysis plan:** Details of how the data will be processed and presented (tables, graphs, figures) for reporting.

3.2.5 Phase 5. Design of Evaluation Forms for the Agroecosystem Intervention

During this phase, the research team will develop a set of standardized forms to be used by key system actors throughout the establishment, implementation, and management of the intervention. These instruments will ensure systematic data collection and facilitate monitoring and evaluation of the intervention's effects. At a minimum, the following forms are proposed:

1. **Farmer Commitment Letter:** This document formalizes the cooperation of participating farmers. It must include the farmer's full name, a statement of interest in participating in the intervention

Table 3: Sample format for recording variable data during the intervention evaluation.

Evaluation name:								
Location (Community, municipality, State)					Date:			
EU	Treatment	Factor A	Factor B	Treatment Description	Block	Variable 1	Variable 2	…Variable n
1								
…								
n								

evaluation, and a commitment to engage in all relevant activities, including establishment, management, and maintenance of the intervention. The letter must also authorize the research team to conduct monitoring, sampling, and data collection throughout the production cycle in accordance with the experimental plan.

2. **Production Unit Logbook:** Each cooperating farmer will maintain a logbook to record all activities conducted in their production unit. The logbook should include a) Cover page, b) General information on the farmer, c) Description of the production unit, d) Design and spatial layout (sketch) of the intervention, e) Detailed activity log. Activities to be recorded include land preparation, planting, cultivation practices, weed, pest, and disease management, harvesting, post-harvest handling, and marketing. Each entry should detail the date, type of activity, cost per hectare, number of laborers, labor cost, equipment or machinery used, and any relevant observations. This information will support the assessment of the intervention's impact and the calculation of selected indicators.

3. **Experimental Logbook:** This logbook will be used by the research team to record all experimental activities. Its structure is defined in the intervention's experimental design section. Each entry must include a description of the activity, location, equipment and materials used, responsible personnel, date, and observations.

3.2.6 Phase 6. Training for the Establishment of Demonstrative Production Units and Data Collection

Training is a fundamental strategy for improving agroecosystems. It enhances understanding of system components, their functions, and interactions, thereby empowering key actors to make informed decisions and solve problems. As highlighted by Mitchell (1995), training contributes to:

- Informed decision-making and problem-solving.
- Confidence, assertiveness, and personal development.
- Effective conflict management.
- Leadership and communication skill development.
- Increased satisfaction and achievement of goals.
- Knowledge growth in diverse fields.
- Overcoming fears related to incompetence or lack of knowledge.

The primary goal is to strengthen the individual and collective capacities of stakeholders, enhance their competitiveness, and familiarize them with the principles of multidimensional, transdisciplinary systemic analysis; the procedures for establishing demonstrative production units; and the proper use and completion of evaluation forms.

Training Process

The training process includes three stages: planning, execution, and evaluation. Planning involves:

1. Identifying priority topics and selecting facilitators with both theoretical and practical expertise, who can communicate effectively using accessible language.
2. Developing tailored workshop programs.
3. Designing and preparing educational materials such as brochures, manuals, presentations, and videos.
4. Securing necessary resources, including venues (e.g., community centers, farms, greenhouses) and technical equipment (e.g., calibration tools for seeders, fertilizer applicators, and sprayers).

Execution consists of delivering training sessions according to the scheduled program, ensuring content is practical and aligned with local conditions. Evaluation and follow-up should be conducted both at the start and conclusion of the training. *Evaluation* tools will be designed to assess practical knowledge in areas such as: Organization and market access, Participatory breeding of crops, Use of certified seed, Efficient application of organic and chemical fertilizers, Integrated weed, pest, and disease management, and Conservation and sustainable use of natural resources (soil, water, biodiversity).

Assessments may be administered through short interviews conducted by technical staff or through direct observation during follow-up visits to production units. To ensure sustained impact, follow-up is recommended for a minimum of three years, and ideally five, allowing iterative learning and reinforcement of improved practices.

Training should be completed before the intervention plots are established, preferably one month prior to the beginning of the agricultural cycle, to allow timely application of acquired knowledge.

3.2.7 Phase 7. Establishment of the Intervention in Field Conditions

This Phase involves the implementation of the agroecosystem intervention under field conditions in two formats:

1. **Demonstration or School Plot,** established within a cooperating farmer's production unit to showcase the effects of the proposed intervention and serve as a hands-on training site for other producers.
2. **Experimental Plot,** implemented by the research team for formal evaluation purposes, which may or may not be located within a farmer's field.

In both cases, detailed planning is essential before implementation. This includes scheduling activities, securing human resources, and preparing required machinery and inputs. Key preparatory activities include:

1. **Scheduling the Sowing Date:** Determine the optimal sowing date based on climatic conditions, availability of labor, machinery, and inputs, as well as the farmer's experience.
2. **Preparing Inputs Based on Experimental Design:** Organize seeds, define fertilizer dosages (chemical or organic), and select weed, pest, and disease control strategies according to the factors and levels outlined in the experimental design.
3. **Soil Preparation:**Prepare the land in alignment with the intervention's goals. This may involve traditional tillage, conservation tillage, minimum tillage, or no-till systems.
4. **Irrigation Planning:** For irrigated systems, schedule irrigation immediately after sowing. For rainfed systems, ensure planting occurs when soil moisture is adequate for seed germination.
5. **Logistics and Labor for Sowing:** Secure appropriate equipment (e.g., automatic/semi-automatic seeders, moldboard plow) and labor (at least five people per hectare using shovels, coa, or manual methods) to carry out sowing activities.

To ensure the robustness and scalability of the results, the intervention should be implemented over at least two agricultural production cycles and at two distinct sites within the target region. This provides a broader range of evaluation conditions and strengthens the validity of the findings.

The establishment and agronomic management of the demonstrative plots offer a valuable opportunity to engage local farmers in participatory learning activities. These may include the calibration of sowing, fertilization, and irrigation equipment. Such involvement enhances the efficient use of seeds, fertilizers, pesticides, soil, and water, key elements for achieving sustainable food production.

Finally, all activities conducted within each demonstration plot must be carefully recorded. These records are essential for evaluating the effectiveness of the intervention and calculating selected indicators.

3.2.8 Phase 8. Monitoring of the Intervention under Field Conditions

Monitoring of the demonstration plots established within the cooperating farmers' production units will be carried out by the multidisciplinary working group organized in Phase 4. Effective communication among stakeholders is essential and should be maintained through mobile phones, email, and digital platforms to ensure timely follow-up of scheduled activities and to address any unforeseen issues that may arise. The research team must remain available to visit the plots and provide support throughout key stages of the production cycle.

Following the establishment of the intervention, monitoring should focus on the scheduled crop management activities from sowing to harvest. For each activity, dates must be defined based on the crop's phenological stage, and the necessary labor, equipment, and inputs must be allocated accordingly.

To promote participatory learning, the active involvement of farmers should be encouraged during the following critical activities:

1. **Weed Management:** Calibration of sprayers, determination of appropriate herbicide doses, and application timing based on weed development stages.
2. **Plant Nutrition:** Identification of nutritional requirements at each crop stage and application of chemical or organic fertilizers accordingly.
3. **Pest and Disease Control:** Use of biological and chemical control strategies, including selection of products, dosage, sourcing, and appropriate timing and methods of application.
4. **Harvest and Post-Harvest Operations:** Calibration of harvesting, cleaning, and sorting equipment, as well as procedures for grain packaging and storage.

Documentation of stakeholder participation is essential. Attendance records, photographs, and videos should be collected during each activity as evidence of engagement. These materials not only serve to track involvement but also act as motivational tools to encourage broader farmer participation and the transformation of agroecosystem through a systemic and transdisciplinary approach.

3.2.9 Phase 9. Data Collection in Experiments and Interventions

Once field variables have been measured and recorded, data collection is carried out collaboratively by the research team and cooperating farmers responsible for field evaluation. The collected data are then entered into a pre-designed database (Table 3), where they are verified for accuracy and completeness. Based on this information, relevant variables and indicators are calculated and subsequently exported to statistical software for analysis.

Maintaining clear, well-organized records is essential to ensure data traceability and to preserve evidence of the work conducted. Original logbooks from the demonstration plots, once the data have been digitized, should be returned to the cooperating farmers. These documents serve as practical references for future agricultural decision-making and contribute to an ongoing, iterative learning process.

3.2.10 Phase 10. Statistical Analysis of Experimental Data and Intervention

Data collected from the experiments and demonstration plots must be analyzed using appropriate methods from the applied sciences involved in the research. Statistical processing is essential to identify significant differences resulting from the variation of experimental factors and their levels. This step ensures that the conclusions drawn from the data are scientifically valid and reliable.

Recommended statistical approaches include both descriptive and inferential methods. Descriptive statistics, such as measures of central tendency, dispersion, and frequency distributions, provide an overview of the data. Inferential techniques, including analysis of variance (ANOVA), multiple comparisons of means, linear and multiple regression, and response surface methodology, help evaluate treatment effects and interactions (Walpole et al., 1999; Martínez, 2008; Montgomery, 2016). Additionally, multivariate methods such as principal component analysis (PCA), cluster analysis, multivariate analysis of variance, and canonical discriminant analysis allow for deeper exploration of complex variable relationships (Kachigan, 1991; Han et al., 2012; Johnson, 2000; Köbrich et al., 2003).

Various statistical software packages are suitable for this type of analysis, including SAS®, Statgraphics Centurion XVIII®, Stata®, IBM SPSS software®, and R Statistical Software®, among others.

Beyond statistical rigor, data analysis must adopt a multidimensional and holistic perspective, in line with the transdisciplinary systemic approach of this methodology. This means interpreting results not only through statistical significance but also in terms of their broader implications for agroecosystem sustainability and performance.

Results should be summarized using selected indicators, enabling comparisons with the baseline values established in Phase 2. This comparative analysis supports the assessment of intervention outcomes across multiple dimensions, economic, social, technological, and environmental, and informs adjustments or improvements to the intervention. Ultimately, this approach ensures that the results are meaningful and actionable for the primary stakeholders in the agroecosystem, contributing to more sustainable and resilient production systems.

3.2.11 Phase 11. Integration and Presentation of Results

This final Phase involves the integration and dissemination of results with the active participation of the research team and cooperating farmers who wish to be involved. The aim is to explain the outcomes of the intervention from a multidimensional perspective, considering the economic, social, technological, and environmental dimensions in an integrated and holistic manner.

To ensure that successful interventions can be adopted and scaled, it is essential to gather feedback from the key stakeholders throughout the process. This participatory feedback strengthens the application of the multifactorial, transdisciplinary, systemic approach and increases the likelihood of achieving meaningful and lasting improvements in the agroecosystem. Starting in the second year, the methodology may be reapplied beginning from Phase 3, with a full cycle repetition possible by the end of the third year, supporting an iterative, adaptive process.

Dual Approach to Dissemination

Results should be presented using two complementary formats, tailored to different audiences:

1. **Farmer-Oriented Communication:** Materials for farmers must be written in clear, accessible language, avoiding technical jargon. These may take the form of brochures, pamphlets, or practical manuals that provide a concise description of the technique or technology, including: the purpose of the intervention, its intended beneficiaries, implementation details (how, when, where, and with what resources), and contact information for technical support. These materials should aim to empower farmers to replicate or adapt the techniques independently. In addition, a simple visual presentation should be prepared to share results during community meetings. These sessions provide a space for dialogue, validation, and collective reflection, further strengthening collaboration and shared ownership of the outcomes.

2. **Scientific Dissemination:** For the academic community, results should be presented in the form of scientific publications, following the conventional structure: title, authors, affiliations, abstract, introduction, material and methods, results and discussion, conclusions, acknowledgments, and references. The exact structure may vary depending on the target journal and its intended audience. Publishing in peer-reviewed journals will contribute to the advancement of knowledge in agroecosystem management and offer a framework for replication in other regions. Furthermore, it supports the organization and coherence of actors involved in agroecosystem transformation through a shared transdisciplinary and systemic vision.

3.3 Application of the MSTAAR Methodology

The Multidimensional, Systemic, and Transdisciplinary Analysis for Agricultural Research (MSTAAR) methodology was applied to enhance the sustainability of a maize agroecosystem through the management and reuse of agro-industrial and agricultural residues, specifically nejayote (a by-product of nixtamalization) and manure. This methodological approach enabled a comprehensive analysis of the production system, the co-design of interventions with stakeholders, and the evaluation of the impacts of those interventions across multiple dimensions.

The implementation of the MSTAAR methodology facilitated the identification of key problems and opportunities in the agroecosystem through collaborative diagnosis; the design of context-specific solutions grounded in scientific, technical, and local knowledge; the monitoring and measurement of changes resulting from the interventions using sustainability indicators; and, critically, the active and ongoing participation of key stakeholders, including farmers, researchers, and institutional actors.

The application of this approach demonstrated that integrating biophysical, social, technological, and economic factors leads to more robust and adaptive solutions, while reinforcing collective capacity for sustainable management. The results of this application, detailing both the processes and outcomes, have been published in Domínguez-Hernández et al. (2018, 2019, 2022), Valderrama et al. (2020), Suazo-López et al. (2025), Domínguez-Hernández et al. (2025).

4 Conclusions

The MSTAAR methodology demonstrates the potential of transdisciplinary research frameworks to generate actionable knowledge and transformative outcomes in agricultural systems. As evidenced in the referenced studies, MSTAAR goes beyond integrating diverse academic perspectives by actively involving local stakeholders in all phases of the research process.

MSTAAR offers a comprehensive, adaptable, and replicable framework for evaluating and improving agricultural production systems. Its flexibility allows for application across diverse environmental, social, economic, and technological contexts, thanks to its general yet adaptable procedures. This makes it a powerful tool for the design, evaluation, and implementation of sustainable agricultural interventions.

A key factor in the success of the MSTAAR methodology is the active, organized, and collaborative participation of the main actors within the system. Such engagement fosters shared responsibility, strengthens institutional and farmer relationships, and increases the likelihood of effective implementation, particularly during the intervention phases. Its successful application in Mexican agroecosystems confirms its potential to generate both scientific and practical knowledge while strengthening local capacities.

The methodology's impact maximized through multi-year application, ideally over at least two agricultural cycles, to allow for iterative learning, adoption of improved practices, and robust evaluation. MSTAAR provides a practical and theoretical foundation for advancing sustainability in agroecosystems through a systemic, participatory, and context-sensitive approach.

Authors' Contribution: Martha Elena Domínguez-Hernández and Rosalba Zepeda-Bautista contributed primarily to the research conception, design, analysis, interpretation of data, and preparing and revising the manuscript.

Funding: There was no external funding received for conducting this study.

Conflicts of Interest: The authors declares that there is no conflict of interest regarding the publication of this paper.

Acknowledgments: The authors thank the Secretaría de Investigación y Posgrado of the Instituto Politécnico Nacional and the Facultad de Estudios Superiores Cuautitlán of the Universidad Nacional Autónoma de México for their financial support, infrastructure, and facilities provided for conducting the research through projects SIP-20171283, SIP-20181180, and FESC-CI 2454. We would like to thank Juan Virgen Vargas†, Master of Science, and Ma. del Rosario Tovar Gómez, Ph. D. for sharing their experiences of participatory work with agricultural producers in the central High Valleys of Mexico.

References

Alaminos, C. A., Castejón, C. J. L., (2006). *Elaboración, Análisis e Interpretación de Encuestas, Cuestionarios y Escalas de Medición.* Marfil.

Alrøe, H. F., Kristensen, E. S. (2002). Towards a systemic research methodology in agriculture: Rethinking the role of values in science. *Agriculture and Human Values*, 19, 3–23. https://doi.org/10.1023/A:1015040009300

Andrade-Cruz, G., Zepeda-Bautista, R., Domínguez-Hernández, M. E., Rodríguez-Ramírez, N. E. (2025). Environmental awareness and action in high school students: A case study in Mexico. *Revista Iberoamericana para la Investigación y el Desarrollo Educativo,* 15(30), e873. https://doi.org/10.23913/ride.v15i30.2391

Astier, C. M., Masera, O. R., Galván-Miyoshi, Y. (2008). *Evaluación de sustentabilidad. Un enfoque dinámico y multidimensional.* Universidad Nacional Autónoma de México.

Bacheva, V., Madison, I., Baldwin, M., Baker, J., Beiltein, M., Call, D. F., Deaver, J. A., Efimenko, K., Genzer, J., Grieger, K., Gu, A. G., Mert, I. M., Liu, J., Li, S., Mayer, B. K., Kumar, A. M., Nino, J. C., Rubambiza, G., Sengers, P., Shepherd, R., Woodson, J., Weatherspoon, H., Frank, M., Jones, J., Sozzani, R., Stroock, A. (2025). Transdisciplinary collaborations for advancing sustainable and resilient agricultural systems. *Global Change Biology,* 31(e70142), 1-16. https://doi.org/10.1111/gcb.70142

Badii, M. H., Castillo, J., Guillen, A. (2008). Tamaño óptimo de la muestra. *Innovaciones de Negocios,* 5(1), 53–65.

Badii, M. H., López-Pérez F., Quiróz H., Pazhakh, A. R. (2004). Muestreo como un requisito fundamental en las acciones experimentales. *Innovaciones de Negocios,* 1(1), 33-53.

Badii, M. H., Guillen, A., Valenzuela, J., Cerna, E., Abreu, J. L. (2011). Muestreo simple aleatorio, binomial, estimación de razón y estratificado: Descripción y análisis comparativo. *International Journal of Good Conscience,* 2(6), 218-240.

Bawden, R. J. (1991). Systems thinking and practice in agriculture.*Journal of Dairy Science,* 74(7), 2362–2373.

Bawden, R. J. (2007). Redesigning animal agriculture: A systemic perspective". In Swain, D. L., Charmley, E., Steel, J., & Coffey, S. (Eds.), (2007). *Redesigning animal agriculture: The Challenge of the 21st Century.* CABI Publishing.

Bawden, R. J., Packham, R. G. (1993). Systemic praxis in the education of the agricultural systems practitioner. *Systems Practice,* 6(1), 7–19. httpS://doi.org/10.1007/BF01059677

Berdegué, J., Sotomayor, O., Zilleruelo, C. (1990). Metodología de tipificación y clasificación de sistemas de producción campesinos de la provincia de Ñuble, Chile. In Escobar, G., & Berdegué, J. (Eds.), (1990). *Tipificación de sistemas de producción agrícola. Santiago, Chile: Red Internacional de Metodologias de Investigacion en Sistemas de Producción.* Editorial Grafica Andes Ltda.

Brunett-Pérez, L., González-Esquivel, C. E., García-Hernández, L. E. (2005). Evaluación de la sustentabilidad de dos agroecosistemas campesinos de producción de maíz y leche, utilizando indicadores. *Livestock Research for Rural Development,* 17(7).

Calla, S., Lécuyer, L., Skrimizea, E., Balian, E., Young, J. (2022). Advancing food system transformation and addressing conflicts through transdisciplinary methodologies: Strengths and limitations of the community voice method, T-Labs, Film-Making and the Miracle Question. *Frontiers in Sustainable Food Systems,* 6(835203), 1-15. https://doi.org/10.3389/fsufs.2022.835203

Calleros-Islas, A. (2019). Sustainability assessment: An adaptative low-input tool applied to the management of agroecosystems in México. *Ecological Indicators,* 105(2019), 386-397. https://doi.org/10.1016/j.ecolind.2017.12.040

Checkland, P., Poulter, J. (2010). Soft systems methodology. In Reynolds, M., & Holwell, S. (Eds.), (2010). *Systems Approaches to Managing Change: A Practical Guide.* Springer publishing.

del Cerro, S. G. (2019). Rapid urbanization, ecology and sustainability: The need for a broad strategy, holism and transdisciplinarity. *Transdisciplinary Journal of Engineering & Science,* 10, 181-198. https://dx.doi.org/10.22545/2019/0128

Domínguez-Hernández, M. E., Zepeda-Bautista R., Valderrama-Bravo M. C., Domínguez-Hernández E., Hernández-Aguilar C. (2018). Sustainability assessment of traditional maize (Zea mays L.) agroecosystem in Sierra Norte of Puebla, Mexico.*Agroecology and Sustainable Food Systems,* 42(4), 383-406. https://dx.doi.org/10.1080/21683565.2017.1382426

Domínguez-Hernández, M. E., Zepeda-Bautista R., Domínguez-Hernández E., Valderrama-Bravo M. C., Hernández-Simón L. M. (2019). Effect of lime water–manure organic fertilizers on the productivity, energy efficiency and profitability of rainfed maize production. *Archives of Agronomy and Soil Science,* 66(3), 370-385. https://doi.org/10.1080/03650340.2019.1616287

Domínguez-Hernandez, M. E., Domínguez-Hernandez, E., Martínez-Barrera, G., Domínguez-Hernandez, A., Zepeda-Bautista, R. (2022). Transdisciplinary Interventions to Improve the Sustainability of Maize Agroecosystems: A Case Study from Mexico. *Transdisciplinary Journal of Engineering & Science,* SP-1, 85-99. https://doi.org/10.22545/2022/00196

Domínguez-Hernández, A., Juárez-Velázquez, A., Domínguez-Hernández, E., Zepeda-Bautista, R., Hernández-Aguilar, C., Domínguez-Hernández, M. E. (2025). Impact of the integration level in crop–livestock systems on biomass production, nutrient recycling, and energy efficiency. *Biomass,* 5(2), 19. https://doi.org/10.3390/biomass5020019

Drugus, L. (2013). Transdisciplinary methodology in research and education: The EMMY Case. *Transdisciplinary Journal of Engineering & Science,* 4, 125-136. https://doi.org/10.22545/2013/00036

Eksvärd, K., Salomonsson, L., Francis, C., Sriskandarajah, N., Svanäng, K., Lieblein, G., Björklund, J., Geber, U. (2009). Participatory Approaches and Stakeholder Involvement in Sustainable Agriculture Research. In Bohlen, P. J. & House, G. (Eds.). *Sustainable Agroecosystem Management: Integrating Ecology, Economics and Society.* CRC Press.

Food and Agriculture Organization of the United Nations (FAO) (2013). SAFA *Sustainability assessment of Food and Agriculture Systems: Indicators.* FAO. Rome. https://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/SAFA_Indicators_final_19122013.pdf (accessed September 22, 2019).

Fernández, G. C., Ollivier, G., Bellon, S. (2020). Transdisciplinarity in agroecology: Practices and perspectives in Europe. *Agroecology and Sustainable Food Systems,* 45(4), 523–550. https://doi.org/10.1080/21683565.2020.1842285

Francis, C. A., Lieblein, G., Breland, T. A., Salomonsson, L., Geber, U., Sriskandarajah, N., Langer, V. (2008). Transdisciplinary research for a sustainable agriculture and food sector. *Agronomy Journal.* https://doi.org/10.2134/agronj2007.0073

Ford, L., Ertas, A. (2024). Systems engineering transformation: Transdisciplinary endeavor. *Transdisciplinary Journal of Engineering & Science,* 15, 1-39. https://doi.org/10.22545/2024/00240

Gasparatos, A., von Maltitz, G., Ahmed, A., Brako, D. E., Pawel, M. J., Saito, O., Luhanga, D., Rigolot, C., Lozano, L. D. P. (2023). Mobilizing participatory approaches to introduce transdisciplinary research elements when exploring the interface of commodity crop production and food security in Sub-Saharian Africa. *Frontiers in Sustainable Food Systems,* 7(1132465), 1-20. https://doi.org/10.3389/fsufs.2023.1132465

Gilbertson, L., Pourzahedi, L., Laughton, S., Gao, X., Zimmerman, J., Theis, T. L., Westerhoff, P., Lowry, G. (2020). Guiding the design space for nanotechnology to advance sustainable crop production. *Nature Nanotechnology,* 15, 801-810. https://doi.org/10.1038/s41565-020-0706-5

Gigch, J. P. (2006). *Teoría General de Sistemas.* Trillas.

Gliessman, S. R., (2015). *Agroecology: The Ecology of Sustainable Food Systems.* CRC Press.

Greenhalgh, G., Alexander, K. S., Larson, S., Thammavong, P., Sacklokham, S., Thephavanh, M., Sinavong, P., Moglia, M., Perez, P., Case. P. (2019). Transdisciplinary agricultural research in Lao PDR. *Journal of Rural Studies,* 72, 216-227. https://doi.org/10.1016/j.jrurstud.2019.10.020

Gutiérrez, P., De la Vara, S. (2012). *Análisis y Diseño de Experimentos.* McGraw-Hill.

Han, J., Kamber, M., Pei, J. (2012). Cluster Analysis: Basic Concepts and Methods. In Kaufmann, M. (Ed.). *Data Mining.* Elsevier Inc. https://doi.org/10.1016/B978-0-12-381479-1.00010-1

Hazard, L., Steayaert, P., Martin, G., Couix, N., Navas, M., Duru, M., Lauvie, A., Labatut, J. (2018). Mutual learning between researchers and farmers during implementation of scientific principles for sustainable development: The case of biodiversity-based agriculture. *Sustainability Science,* 13, 517-530. https://doi.org/10.1007/s11625-017-0440-6

Hernández-Aguilar, C. (2018). Transdisciplinary methodological option for initial research process: Training of researchers. *Transdisciplinary Journal of Engineering & Science,* 9, 157-181. https://doi.org/10.22545/2018/00108

Hernández-Aguilar, C., Saucedo, D. A., Domínguez, P. A., Valderrama, B. M. C., Igno, R. O., Valencia, H. E., Mundo, F. Z., Ivanov, R., Martínez, O. E. J. (2023). Transdisciplinarity for sustainable development: Incorporating organic waste into bread-making. *Transdisciplinary Journal of Engineering & Science,* 14, 141-161. https://doi.org/10.22545/2020/00227

Johnson, D. E., (2000). *Métodos Multivariados Aplicados al Análisis de Datos.* International Thomson Editores.

Kachigan, S. K., (1991). *Multivariate Statistical Analysis: A Conceptual Introduction.* Radius Press.

Köbrich, C., Rehman, T., Khan, M. (2003). Typification of farming systems for constructing representative farm models: Two illustrations of the application of multi-variate analyses in Chile and Pakistan. *Agricultural Systems,* 76(1), 141–157. https://doi.org/10.1016/S0308-521X(02)00013-6

Koppelmäki, K., Helenius, J., Schulte, R. P. O. (2021). Nested circularity in food systems: A Nordic case study on connecting biomass, nutrient and energy flows from field scale to continent. *Resources, Conservation and Recycling,* 164(105218). https://doi.org/10.1016/j.resconrec.2020.105218

Liang, D., Tang, W., Fu, Y. (2023). Sustainable modern agricultural technology assessment by a multi-stakeholder transdisciplinary approach.*IEEE Transactions on Engineering Management,* 70(3), 1061-1075. https://doi.org/10.1109/TEM.2021.3097333

López-Ridaura, S., Masera, O., Astier, M. (2000). Evaluating the sustainability of integrated peasantry systems-The MESMIS Framework.*Ecological Indicators,* 2, 28–30.

López-Ridaura, S., Masera, O., Astier, M. (2002). Evaluating the sustainability of complex socio-environmental systems. The MESMIS framework. *Ecological Indicators,* 2(1), 135–148.

Malhotra, N. K., (2004). *Investigación de Mercados. Un Enfoque Aplicado.* Pearson Educación.

Martínez, G. A., (1996). *Diseños Experimentales: Métodos y Elementos de Teoría.* Trillas.

Mascarenhas, A., Coelho, P., Subtil, E., Ramos, T. B. (2010). The role of common local indicators in regional sustainability assessment. *Ecological Indicators,* 10(3), 646–656. https://doi.org/10.1016/j.ecolind.2009.11.003

Masera, O., Astier, M., López-Ridaura, S. (1999). *Sustentabilidad y Manejo de Recursos Naturales: El Marco MESMIS.* Mundi Prensa.

Meadows, D., (2008). *Thinking in systems: A primer.* Earthscan.

Measham, T. G., Preston, B. L., Smith, T. F., Brooke, C., Gorddard, R., Withycombe, G., Morrison, C. (2011). Adapting to climate change through local municipal planning: Barriers and challenges. *Mitigation and Adaptation Strategies for Global Change,* 16(8), 889–909. https://doi.org/10.1007/s11027-011-9301-2

Mitchell, G., (1995). *Manual del Capacitador.* Grupo Editorial Iberoamerica.

Mokiy, V. (2019). Using the systemic-transdisciplinary approach to enhance the operational reliability and maintenance programming of complex technical objects. *Transdisciplinary Journal of Engineering& Science,* 10(1), 133-145. https://doi.org/10.22545/2019/0124

Mokiy, V., Lukyanova, T. (2019). Imperatives of sustainable development from the perspective of transdisciplinary systems approach. *Transdisciplinary Journal of Engineering & Science,* 10, 169-180. https://doi.org/10.22545/2019/0127

Montgomery, D. C. (2016). :*Diseño y Análisis de Experimentos.* Limusa.

Ostrom. E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science,* 325(5939), 419-422. https://doi.org/10.1126/science.1172133

Otzen, T., Manterola, C. (2017). Técnicas de muestreo sobre una población a estudio. *International Journal Morphology,* 35(1), 227-232.

Reed, M. S., Fraser, E. D., Dougill, A. J. (2006). An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics,* 59(4), 406–418. https://doi.org/10.1016/j.ecolecon.2005.11.008

Restrepo, M. J., Lelea, M., Kaufmann, B. (2020). Assessing the quality of collaboration in transdisciplinary sustainability research: Farmers' enthusiasm to work together for the reduction of post-harvest dairy losses in Kenya. *Environmental Science & Policy,* 105, 1-10. https://doi.org/10.1016/j.envsci.2019.12.004

Sánchez, G. G., Cortés, Z. J. (2019). Transdisciplinary theory of Mexican agricultural knowledge: Semiotics, communication and anthropology. *Transdisciplinary Journal of Engineering & Science,* 10, 72-80. https://doi.org/10.22545/2019/0118

Siebrecht, N. (2020). Sustainable agriculture and its implementation gap-overcoming obstacles to implementation. Sustainability, 12(9), 3853. https://doi.org/10.3390/su12093853

Schindler, J., Graef, F., König, H. J., Mchau, D., Saidia, P., Sieber, S. (2016). Sustainability impact assessment to improve food security of smallholders in Tanzania. Environmental Impact Assessment Review, 60, 52–63. https://doi.org/10.1016/j.eiar.2016.04.006

Schindler, J., Graef, F., König H. J. (2015). Methods to assess farming sustainability in developing countries. A review. Agronomy for Sustainable Development, 35(3), 1043–1057. https://doi.org/10.1007/s13593-015-0305-2

Sokal, R. R. (1977). Clustering and classification: Background and current directions. In Van Ryzin, J. (Ed.). *Classification and Clustering.* Academic Press.

Suazo-López, F., Hernández-Aguilar C., Ramírez-Arias J. A., Zepeda-Bautista R., Domínguez-Hernández M. E. (2025). Sustainability analysis of the greenhouse tomato (Solanum lycopersicum L.) production system. *Journal of Applied Biology & Biotechnology,* 13(2), 32-43. https://doi.org/10.7324/JABB.2025.211953.

Vilsmaier, U., Brandner, V., Engbers, M. (2017). Research in-between: The constitutive role of cultural differences in transdisciplinarity. *Transdisciplinary Journal of Engineering & Science,* 8, 169-179. https://doi.org/10.22545/2017/00093

Walpole, R. E., Myers, R. H., Myers, S. L. (1999). *Probabilidad y Estadística para Ingenieros.* Prentice-Hall Hispanoamericana.

Wickson, F., Carew, A. L., Rusell, A. W. (2006). Transdisciplinary research: Characteristics, quandaries and quality. *Futures,* 38, 1046-1059. https://doi.org/10.1016/j.futures.2006.02.011

Zahm, F., Viaux, P., Vilain, L., Girardin, P., Mouchet, C. (2008). Assessing farm sustainability with the IDEA method-from the concept of agriculture sustainability to case studies on farms. *Sustainable Development,* 16, 271-281. https://doi.org/10.1002/sd.380

Zepeda-Bautista, R., Virgen-Vargas, J., Suazo-López, F., Arellano-Vázquez, J. L., Avila-Perches, M. A. (2021). Nitrogen in fertigation to produce seed of parental lines and simple crosses of maize: Doses and distribution.*Revista Fitotecnia Mexicana,* 44(2), 191–200. https://doi.org/10.35196/rfm.2021.2.191

Zcheischler, J., Brunsch, R., Rogga, S., Scholz, R.W. (2022). Perceived risks and vulnerabilities of employing digitalization and digital data in agriculture–Socially robust orientations from a transdisciplinary process. *Journal of Cleaner Production,* 358(132034), https://doi.org/10.1016/j.jclepro.2022.132034