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Participatory Sustainability Indicators Reveal Systemic Weaknesses in Basic Grains Production in Central America

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ABSTRACT

The objective of this study is to establish a system of indicators that enables the rapid collection of information to measure sustainability in basic grains production in the municipality of San Miguel (El Salvador), results that can be extrapolated to any rural community in Central America. We employed a mixed-methods approach, engaging various sectors directly involved in basic grains production. During the fieldwork phase, data were collected using focus groups, interviews, and surveys in five farming communities where an international cooperation project is currently underway. The results indicate that, economically, crop yields, sales profits and labor requirements are low compared to national averages. On the social aspect, health services are located at least 5 km away, there is no access to potable water in homes, and farmers generally have low levels of formal education. Regarding the environmental aspect, farmers use chemicals that are harmful to human health and degrade the soil, and they lack irrigation systems that could increase the number of harvests per year and improve resource efficiency. In conclusion, these findings clearly demonstrate the low levels of social, economic and environmental sustainability in these communities and among their inhabitants.

1 | Introduction

Currently, the global population is growing at an annual rate of 1.3%. It is estimated that the world population will increase from 7.4 billion in 2016 to 8.1 billion in 2025 and 9.6 billion in 2050, with the majority of this increase occurring in developing countries. To feed the world's population in 2050, it is estimated that global agricultural productivity would have to increase by 70% [1]. In this context, it is important to consider the challenges posed by climate change, as climate and agriculture are strongly interrelated. Any significant change in climate patterns is likely to have a devastating impact on agricultural productivity [2]. Beyond food production, agriculture plays a crucial role in the economies of all nations. It is considered a matter of national security in several countries and is recognized as a key productive sector for reducing poverty rates [3, 4].

Agriculture is a critical sector in Latin America (a region rich in natural resources) and plays a key role in global food security [5]. The region contains about one-quarter of the world's arable land and holds roughly one-third of the planet's freshwater supply. Consequently, Latin America accounts for 15% of global food exports and is the largest net food-exporting region in the world [5]. The Central America and Mexico (CAM) region includes the tropical and subtropical zones of the North American continent, encompassing Mexico, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama. This area features a wide range of agroecological conditions, from tropical rainforests to high-altitude arid zones. Agricultural systems in CAM also differ significantly from some of the most productive and technologically advanced systems (such as those used for palm oil, tobacco and coffee) to manual, subsistence-based farming systems [6]. In the CAM region, smallholders and subsistence farmers make up the majority of producers. Their productivity is generally low, and many struggle to earn a decent living. These farmers primarily grow basic grains, which are essential in daily diets due to their nutritional content. Key crops in the region include corn, beans, wheat and rice [7]. In El Salvador, corn, beans and sorghum are the main crops in 196 of the country's 262 municipalities [8]. Throughout CAM, corn and bean production is the main strategy used to ensure household food security [6]. Despite their social importance, these farming systems occupy only a small share of the region's arable land. For example, in El Salvador, smallholder farmers represent 86% of producers but cultivate only 17% of the land [6].

The social, economic and environmental challenges associated with basic grain farming in the CAM region demonstrate the need for improved indicators of sustainable agriculture. However, developing such indicators presents several challenges. First, the concept of sustainable agriculture is continuously evolving, often caught between oversimplification and excessive specificity. A basic definition of sustainable agricultural systems as "those capable of persevering" is clearly insufficient giving the complexity and dynamism of agricultural systems [9]. Yet, embracing this complexity makes it difficult to compare results or derive insights from systematic monitoring and evaluation methods [10]. Adding to this challenge is the wide range of interpretations of sustainability itself, which often vary significantly (and sometimes strategically) depending on stakeholders' perspectives [11]. Although there is general consensus that agricultural sustainability must address three core dimensions (environmental, social and economic), the specific meaning and prioritization of these dimensions and their subcomponents depend heavily on particular social, environmental and political–economic contexts [12]. As a result, key indicators of sustainability for large-scale industrial farms in the United States or Western Europe often differ markedly from those relevant to smallholder farms in the CAM region or elsewhere in the Global South, even if some indicators overlap. This variation makes standardizing agricultural sustainability assessments extremely challenging. Nonetheless, the promotion of sustainable agriculture remains a cornerstone of the 2030 Sustainable Development Agenda, as it underpins the achievement of several Sustainable Development Goals (SDGs), particularly those related to poverty reduction, food security, and equitable access to natural resources such as land, water and biodiversity [13]. Agricultural production involves a complex set of processes, inputs and outputs, further complicating efforts to establish standardized frameworks for assessing agricultural sustainability [12].

One key response to these challenges has been to emphasize the integration of local knowledge through community participation in the development of sustainability indicators. This approach enables indicators to more accurately reflect and address diverse social, economic and ecological conditions [14], which is particularly important in the highly heterogeneous context of many developing countries [15]. While a wide range of environmental indicators for assessing agricultural sustainability has been developed, significantly fewer indicators have been designed to capture the economic and social dimensions of agricultural systems [16]. Moreover, many existing agricultural sustainability assessment frameworks in developing countries are based on sustainability impact assessment (SIA) methodologies, which tend to be limited in their applicability at the local level [17]. To address these limitations, direct sustainability measurement (DSM) approaches should be implemented at the local scale in developing countries. These methodologies should incorporate community participation to ensure that local knowledge and expertise are effectively integrated into sustainability assessments [17].

This study aims to develop a set of agricultural sustainability indicators using a DSM framework, implemented through a participatory indicator-based (PIB) approach. The practical application of this methodology was carried out in basic grain farming communities in the municipality of San Miguel (El Salvador), agricultural systems that had not been previously analyzed. In doing so, we offer a methodological contribution that explicitly links sustainability concepts to actionable community-level measurement, as detailed in the following section.

2 | Materials and Methods

This section outlines the methodological procedures employed to develop and implement the indicators using a PIB approach in basic grain farming communities in San Miguel, El Salvador. First, the indicator system designed to assess agricultural sustainability is described in detail. Subsequently, the data collection process, sampling strategy, and statistical analyses conducted to evaluate sustainability levels and test the study hypotheses are presented.

2.1 | Measurement of Sustainability Based in Indicators Systems

Sinisterra-Solis et al. [18] emphasize the value of indicator-based approaches for assessing sustainability in agricultural systems. These indicators enable a multidimensional evaluation (environmental, economic and social components) and facilitate the comparison of production systems across different regions. The use of composite and participatory indicators to assess agricultural sustainability is supported by recent empirical studies. For example, Kong et al. [19] demonstrate that variables such as access to credit, use of machinery, crop diversity and income variability can effectively quantify sustainability in production contexts, such as urban agriculture.

The use of indicator lists is the most common approach for assessing various aspects of sustainability in agricultural systems. Indicators such as credit availability, farmer well-being and related socioeconomic factors can be employed to establish a framework for evaluating on-farm sustainability [20]. These indicators are also aligned with specific SDGs and targets, as shown in Table 1.

This study adopted methodological elements from Rao et al. [22], who developed a quantitative framework to assess agricultural sustainability in dryland regions in India. Their research utilized a set of indicators categorized into ecological, economic, and social dimensions, enabling a comprehensive assessment of farmers' sustainability profiles. Similar to our approach, their framework was based on measurable variables such as income, crop diversity, input use, and access to services. In this article, we apply both

TABLE 1 | List of indicators commonly used to measure sustainability in agricultural systems.

Agriculture indicators	Example	SDG target
Yield	Kg product/ha	2.3 Double agricultural productivity and incomes
Yield gap	Attainable yield Actual yield	
Input efficiency	kg grain/kg N	2.4 Sustainable agriculture
Labor productivity	kg product/labor time (days or hours)	2.3 Double agricultural productivity and incomes
Cropping intensity	Crop rotations/year	
Fodder production	Tons/year	
Input use intensity	kg pesticides/ha	
Stocking rate	Animals/ha	
Environment indicators	**Example**	**SDG target**
Soil quality		
Soil carbon	% soil organic matter	2.4 Sustainable agriculture. 13.2 Integrate climate measures into national policy 15.3 Reverse land degradation
Soil erosion	kg/ha	2.4 and 15.3
Nutrient balance	N applied/N harvested	2.4, 13.2 6.3 Improve water queality 6.6 Protect aquatic exosystems. 14.1 Reduce marine pollution
Soil fertility	pH	2.4 and 15.3
Biodiversity		
Population size	Number of individuals	15.1 Protect terrestrial ecosystems 15.2 Sustainable forest management 15.5 Halt biodiversity loss
Species richness	Number of rare species	
Habitat area	Wetland extent	
Greenhouse gas emissions	T CO_2 eq	2.4 Sustainable agriculture 13.2 Integrate climate measures into national policy
Water quality	Mg pollutant/mL	6.3 Improve water quality 6.6 Protect aquatic ecosystems
Water quantity	m^2	6.4 Increase water use efficiency 6.6 Protect aquatic ecosystems
Land cover type/change	% Converted	15.1 Protect terrestrial ecosystems 15.5 Halt biodiversity loss
Human well-being indicators		
Agricultural income	$/ha	2.3 Double agricultural productivity and incomes
Poverty	% Population below poverty line	1. End extreme poverty 2. 1.2 Reduce poverty by half according to national definitions
Employment	On-and-off-farm employment rate	8.5 Employment for all
Food security		
Food availability	Calories/head	2.1 End hunger 2.3 Double agricultural productivity and incomes
Food access	% Income spent on food	2.1 End hunger
Dietary intake	Calories/head	2.1 End hunger 2.2 End malnutrition

(Continues)

TABLE 1 | (Continued)

Environment indicators	Example	SDG target
Food utilization	% Food waste	12.3 Halve global food waste
Nutrition	% Stunting % Obesity	2.1 End hunger 2.2 End malnutrition
Empowerment	Women's empowerment in agriculture Index	5.5 Ensure equal opportunity for women

Note: This table summarizes the indicators used to measure sustainability in agricultural systems, in accordance with the most recurrent agricultural sustainability indicators identified across recent studies [18, 19, 21–23], and their alignment with the Sustainable Development Goals (SDGs).

descriptive and inferential statistical analyses (including chi-square tests) to compare sustainability outcomes among different groups of basic grain producers in San Miguel, El Salvador. This methodological alignment strengthens the validity of using composite indicators and statistical tools to assess sustainability in smallholder farming systems characterized by diverse socioeconomic conditions.

Furthermore, multidimensional and participatory frameworks have increasingly served as methodological references for assessing sustainability in agricultural systems. For example, [18] developed a system of composite indicators based on multicriteria decision analysis, integrating environmental, economic and social dimensions, while emphasizing stakeholder participation. Similarly, Zhan et al. [20] introduced the sustainable agriculture matrix, a structured indicator framework aligned with the SDGs, enabling comprehensive sustainability assessment across diverse contexts. These approaches support the use of composite and participatory indicators, especially in smallholder systems characterized by varied socioeconomic and agroecological conditions. Based on this knowledge, the present study employs descriptive and inferential statistical methods (chi-square tests) to evaluate sustainability outcomes among basic grain producers in eastern El Salvador, using indicators adapted to the local context. This comparative analysis aims to identify opportunities for innovation and improvement in agricultural practices. In this regard, Musumba et al. [24] propose a systematic procedure for measuring sustainability that includes:

1. Selection of sustainability domains to be assessed: including the domains of productivity, economic, environment, human condition, and social domain. The productivity domain recognizes soil as a critical resource and considers the various inputs and resources used for agriculture. The economic domain focuses primarily on farm profitability, as well as farmers' decision-making processes in response to market demands and production costs. The environmental domain addresses the impacts of agricultural activities on natural resources, including land, water and biodiversity. The human condition domain refers to individual well-being, encompassing aspects such as food security, learning capacity, and the ability to adapt to change. And the social domain concerns the social interactions among individuals within farming communities.
2. Select the analysis scale: the analysis scale defines the parameters for data collection and the methods by which data will be gathered. A comprehensive sustainability assessment often requires the use of multiple analytical scales, particularly when examining the interrelationships among different sustainability domains. Employing various scales enhances the ability to capture complex dynamics across environmental, economic, and social dimensions.
3. Determination of indicators: a comprehensive list of sustainability indicators is initially compiled through an extensive literature review and consultations with other researchers. This preliminary list is then refined in collaboration with stakeholders through participatory analysis, leading to the identification of a context-appropriate and representative set of indicators.

Building on the general framework for sustainability assessment and the recommendations by Musumba et al. [24] regarding the selection of domains, analytical scales, and indicators, this study developed a context-specific set of indicators tailored to the realities of basic grain farmers in eastern El Salvador. The indicator selection process was informed by three main sources: (i) a review of relevant literature and alignment with the SDGs; (ii) secondary data from technical reports published by the Ministry of Agriculture and other public institutions; and (iii) diagnostic interviews with farmers and rural development experts. Drawing on these inputs, the study developed a set of 16 operational indicators designed to capture key dimensions of productivity, profitability, diversification, access to services, and socioeconomic conditions. Data were collected through a structured 25-question survey administered to participating farmers.

It is important to note that some commonly cited indicators in the literature (such as greenhouse gas emissions and biodiversity) were excluded due to limited direct data availability and the technical complexity involved in measuring them within the local context. However, proxy variables were incorporated to indirectly capture these dimensions, including agrochemical use, cropping intensity, and crop diversity. This approach enabled the development of an assessment system adapted to the available data while maintaining the multidimensional integrity of the sustainability concept.

2.2 | Adaptation of the Applied Methodology for Sustainability

This study employs a mixed-methods approach to assess sustainability in smallholder agricultural systems in San Miguel, El Salvador. Both quantitative and qualitative data were collected using

TABLE 2 | Relation between indicators, questions, and item-total correlation results posed to farmers in San Miguel, El Salvador.

Dimension	Indicator	Question	Item-total correlation	Classification
Economic	1. Crop productivity	What is your production capacity (quintals)?	0.17[a]	Low (<0.3)
		Average yield of the last year (quintals)	0.349	Moderate (0.3–0.5)
		Do you use an agricultural production plan?	0.59	High (>0.5)
	2. Real costs crop productivity	Do you know your fixed, variable costs and break-even point?	0.585	High (>0.5)
		What are your costs per crop of basic grains?	0.4	Moderate (0.3–0.5)
	3. Profitability	Selling price of last harvest? Per quintal	0.292	Moderate (0.3–0.5)
		Range of profit for basic grains?	0.417	Moderate (0.3–0.5)
	4. Cultivation intensity	How many crops a year from basic grains?	0.133[a]	Low (<0.3)
	5. Products diversity	Do you grow other crops besides basic grains?	0.301	Moderate (0.3–0.5)
	6. Production plan	Type of accounting record used?	0.206[a]	Low (<0.3)
	7. Job requirement	Man-hours needed to grow 1 hectare?	0.079[a]	Low (<0.3)
Social	8. Area availability for crop	Size of the area cultivated?	0.006[a]	Low (<0.3)
	9. Basic services disponibility	Access to electricity and drinking water?	0.326	Moderate (0.3–0.5)
		Distance to nearest health center	0.386	Moderate (0.3–0.5)
		Distance to nearest school	0.108[a]	Low (<0.3)
	10. Expenses on basic services	Average electricity cost (including crops/livestock)?	0.128[a]	Low (<0.3)
		Average water cost (including crops/livestock)?	0.107[a]	Low (<0.3)
	11. Employment	Number of months worked/year?	0.317	Moderate (0.3–0.5)
		Years of experience in grain farming	0.212[a]	Low (<0.3)
	12. Food diversity	What did you eat yesterday (meals)?	—	—
	13. Use of loans	Origin of capital for cultivation?	0.311	Moderate (0.3–0.5)
	14. Use of machinery	Machinery used in basic grain crops?	0.398	Moderate (0.3–0.5)
Enviromental	15. Water availability	Irrigation system available?	0.173[a]	Low (<0.3)
	16. Active ingredients applied per hectare	Chemical use per hectare?	0.343	Moderate (0.3–0.5)

Note: Item-total correlation analysis for the questionnaire is used to assess sustainability indicators across economic, social, and environmental dimensions. The classification of each item is based on the strength of its correlation with the total score of its respective dimension: high (>0.5), moderate (0.3–0.5), and low (<0.3). Items with values below 0.3 are considered weakly associated and candidates for review or removal, following criteria established by Krabbe [25].
[a]Not considered for the indicators.

a structured survey instrument comprising 16 sustainability indicators (Table 2). This methodological design builds upon previous empirical studies that have successfully utilized quantifiable and comparable indicators to evaluate agricultural sustainability. For example, Kong et al. [19] used participatory and statistical methods to measure sustainability in urban agriculture; Oyinbo et al. [26] developed a composite index using weighted indicators in Nigeria; and Rao et al. [22] conducted a multidimensional analysis to assess dryland farming systems in India.

To analyze the data, the study employed descriptive statistics (including means, standard deviations and frequency distributions) to establish baseline profiles of the farmers. In addition, inferential statistical methods, specifically the chi-square test (χ^2), were used to assess differences in sustainability levels among farmer groups categorized by key variables, such as access to credit, use of machinery, crop diversification and record-keeping practices.

Each indicator was assigned to one of the three sustainability dimensions (economic, environmental and social) and transformed into a three-level scale (low, medium and high) using cut-off points derived from the data distribution. This approach enabled the construction of composite profiles for a more holistic assessment of sustainability.

The interpretation of sustainable agriculture indicators depends on the analysts' perspectives; therefore, a single, universal methodology for evaluating sustainable agriculture is not feasible. One way to address this challenge is to adopt a holistic view of the system and standardize the concept through the use of reference benchmarks. This allows for the subsequent selection of context-specific parameters and criteria. In other words, it is first necessary to understand the significance of agricultural systems before developing appropriate methods and metrics to assess the sustainability of specific agricultural contexts [27].

The adaptation of the direct method for measuring sustainability, along with a participatory approach involving relevant stakeholders, was carried out as follows:

1. Facilitating stakeholder participation: focus groups were conducted with agricultural input suppliers, basic grain distributors, cooperatives and nongovernmental organizations to identify information gaps regarding farmers' sustainability. A literature review was also conducted to identify indicators relevant to the context of farmers in San Miguel. Based on this review, scoring criteria and threshold values were established for each selected indicator.
2. Instrument design: a data collection instrument was developed for use with farmers, incorporating predefined answer choices coded with corresponding scores. This instrument was administered via an online platform.
3. Data processing: the collected data from all participating farmers were organized and tabulated.
4. Indicator calculation: values for each indicator were calculated using the responses aligned with the three sustainability dimensions: social, economic and environmental.

2.3 | Statistical Hypotheses

To complement the descriptive findings, a series of chi-square tests (χ^2) were performed to evaluate the statistical associations between key agricultural practices and the level of sustainability achieved by basic grain farmers. The variables were categorized based on production-related behaviors (such as knowledge of production costs, use of machinery, credit access and crop diversification), and their association with economic and social sustainability dimensions was assessed. This inferential analysis supports a more precise interpretation of how specific practices influence sustainability outcomes and reinforces the value of incorporating quantitative methods into sustainability assessment frameworks. Table 3 summarizes the hypotheses tested along with the corresponding statistical results.

These inferential findings confirm that specific agricultural practices are statistically associated with higher levels of sustainability. Consequently, the integration of quantitative tools enhances the analytical rigor and precision of sustainability assessments in smallholder farming systems.

To assess the relationship between sustainability levels and specific agricultural practices among basic grain farmers in San Miguel, four statistical hypotheses were formulated. These hypotheses were designed to test whether certain practices (such as using a production plan, selling based on real costs, crop diversification and access to machinery or credit) are significantly associated with higher levels of economic or social sustainability.

Each hypothesis was tested using the chi-square test of independence, an appropriate method for analyzing relationships between categorical variables. Farmers were grouped according to their responses (e.g., with or without access to credit, with or without a production plan), and their sustainability levels were classified into three levels (low, medium, and high) based on a scoring system aligned with the established sustainability indicators. The hypotheses tested were as follows:

- H_1: basic grain farmers who sell their agricultural products based on their actual production costs exhibit a level of economic sustainability comparable to that of farmers who do not base their sales on actual production costs.
- H_2: basic grain farmers in San Miguel who implement an agricultural production plan demonstrate a level of economic sustainability comparable to that of farmers without such a plan.
- H_3: basic grain farmers in San Miguel who have access to credit and machinery exhibit a level of social sustainability similar to that of farmers without access to these resources.
- H_4: basic grain farmers who cultivate multiple crops demonstrate a level of economic sustainability comparable to that of farmers who cultivate only corn and/or beans.

The standard deviation was also calculated, and the data were assumed to follow a normal distribution given the sample size exceeded 30 subjects ($n = 141$). A significance level of $\alpha = 0.05$ was applied to test the following null and specific hypotheses:

- H_0: basic grain farmers have an individual dietary diversity score of fewer than four food groups.
- H_1: basic grain farmers have an average individual dietary diversity score of four food groups.

Based on [28], the following formulas were utilized:

$$H_1 = \bar{x} \geq 4,$$

$$H_0 = \bar{x} < 4.$$

The equation used to calculate the Z statistic is presented below:

$$Z = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}.$$

Each hypothesis was tested at a significance level of $\alpha = 0.05$ with 2 degrees of freedom, based on 2×3 contingency tables. Additional details regarding calculations of the other four hypotheses are provided in Table 3.

2.4 | Focus Group Development

In the qualitative phase of the study, a nonprobabilistic convenience sampling method was employed due to the need to access specialized information on community dynamics, agricultural production, and international cooperation within the context of the municipality of San Miguel. This sampling approach was deemed appropriate given the accessibility and subject-matter expertise of the participants, aligning with qualitative research paradigms that emphasize depth and richness of information over statistical representativeness [28].

In addition, a purposive sampling strategy was employed to ensure the participation of key stakeholders with direct experience in the implementation of agricultural projects. According to Palinkas

TABLE 3 | Results of the hypothesis tests.

Hypothesis	Groups	Test statistics and reference values	Conclusion
Basic grain farmers who sell their agricultural products based on their actual costs of production have a level of economic sustainability equal to farmers who do not sell their agricultural products based on their actual costs of production	Farmers who know their fixed and variable production costs, separating them from the group of farmers who do not know these production costs	Calculated chi-square value: 12.08 Degrees of freedom: $df=(r–1)(c–1)=2\alpha=0.05=5\%$ Critical value: 5.99 Decision criterion: The null hypothesis is rejected when the calculated value is greater than the critical value Decision: The null hypothesis is rejected	Farmers who sell their products based on production costs have a higher level of economic sustainability than farmers who do not sell their products based on production costs
The number of basic grain farmers in San Miguel who apply an agricultural production plan shows a level of economic sustainability equal to those farmers who do not have one	Farmers who use a production plan and the second group the farmers who do not have a production plan	Calculated chi-square value: 5.22 Degrees of freedom: $df=(r–1)(c–1)=2$ $\alpha=0.05=5\%$ Critical value: 5.99 Decision: The null hypothesis is accepted	Basic grain farmers who have an agricultural production plan show a level of economic sustainability equal to those farmers who do not
The number of basic grain farmers in San Miguel who have access to credit resources and machinery shows the same level of social sustainability as those who do not have access to these resources	Farmers who do not use machinery for their crops and the second group is made up of farmers who use at least one type of machine to grow their crops	Calculated chi-square value: 96.55 Degrees of freedom: $df=(r–1)(c–1)=2$ $\alpha=0.05=5\%$ Critical value: 5.99 Decision: The null hypothesis is rejected	Basic grain farmers who have access to credit resources and use machinery have a higher level of social sustainability than those farmers who do not have access to these services
Basic grain farmers who grow various products have the same level of economic sustainability as those who only grow corn and/or beans		Calculated chi-square value: 54.435 Degrees of freedom: $df=(r–1)(c–1)=2$ $\alpha=0.05=5\%$ Critical value: 5.99 Decision: The null hypothesis is rejected	Basic grain farmers who grow various products have a higher level of economic sustainability than those who only grow beans and corn

Note: The table presents the hypotheses tested, the groups compared, and the main test statistics (χ^2, degrees of freedom, significance level α, and critical value) along with the decision rule and final conclusion. A significance level of $\alpha=0.05$ was used as the criterion for rejecting or accepting the null hypothesis. *Source:* Authors' calculations based on survey data (2023).

et al. [29], purposive sampling enables the integration of findings from diverse sources and supports the collection of complementary evidence, thereby facilitating a more comprehensive understanding of the phenomenon under study.

Participants were selected using a purposive sampling strategy, prioritizing individuals with direct experience and relevant knowledge in the production and commercialization of basic grains in the department of San Miguel. The selected profiles included marketing agents, agricultural input distributors and small-scale machinery service providers.

Inclusion criteria:

1. Women or men serving as directors, legal representatives, or delegates of NGOs, cooperatives, banks, or foundations working with farmers.
2. Availability to attend the focus group session.
3. Experience in managing international cooperation projects focused on agriculture.
4. Knowledge of the territory of the municipality of San Miguel.
5. Recognition as community leaders.
6. Being over 21 years of age.

Exclusion criteria:

1. Being underage.
2. Lack of experience in community work.
3. Limited availability to participate in the study.

4. Participation in an individual capacity without representing a professional group or institution.

The scoring of each indicator can be determined through expert surveys, with scales designed to capture either quantitative or qualitative values [30]. In their study on local sustainability indicators in Portugal, Moreno and Fidélis [31] employed both qualitative and quantitative data collection tools, including surveys aimed at identifying the number of sustainable development indicators in use. In the context of this research, data collection instruments were designed to gather information from farmers and to generate indicator levels based on national averages published by the Ministry of Agriculture and Livestock (MAG).

2.5 | Questionnaire and Survey to Farmers

For the development of the questionnaire, data provided by stakeholders in the agricultural value chain who participated in the focus group were taken into consideration. These data, along with the study variables, informed the design of the instrument used to collect information from farmers.

The survey administered to basic grain farmers was carried out using online software, accessible via the survey team's mobile devices. QuestionPro software was used to facilitate the process, enabling automatic tabulation and coding of responses for classification according to the corresponding indicators. The software provides an intuitive platform for survey creation and supports various question types. Additionally, QuestionPro generates survey result reports that can be exported in multiple formats. For this study, results were exported in XLS format. The platform also allows monitoring and control of the number of surveys completed.

2.6 | Zone of the Study and Sample

The study was carried out in San Miguel, specifically in seven cantons located on the outskirts of the city: Las Delicias Canton, Las Hojas hamlet, El Papalón Canton, Hernández neighborhood, El Papalón Canton, Las Peñitas hamlet and Cantora Canton. San Miguel is part of the Central America's Dry Corridor, which generates a higher vulnerability to producers due to prolonged drought or excessive rainfall. In these cantons of San Miguel, basic grains such as corn, beans and sorghum are mainly produced; therefore, these crops were selected as the focus of the study. Community engagement was facilitated through collaboration with the FAO RECLIMA project and extension agents from CENTA. A total of 141 basic grain farmers were surveyed. Data were analyzed using descriptive statistics in Excel, as well as hypothesis testing for the mean and chi-square tests.

The majority of the farmers surveyed were men, predominantly aged between 35 and 44 years. The average family size ranged from 3 to 4 members. Regarding landholding size, the cultivated area varied between 1 and 3 hectares. Table 4 presents the descriptive statistics of the surveyed farmers.

TABLE 4 | Descriptive statistics of the farmers in San Miguel, El Salvador.

Aspect	Answers	Percentage
Years of agricultural experience of basic grains (years)	2 years or less	5%
	3–5	21%
	6–10	23%
	11 or more	51%
Size of the area cultivated with basic grains (hectares)	1–3	87.5%
	4–8	6.3%
	8–10	0.8%
	More than 10	0.0%
	0.5	5.5%
Form of tenure of the land that you cultivate	Rented	62.50%
	Shared	6.25%
	Borrowed	16.41%
Family size (Members)	1–2	15.27%
	3–4	45.80%
	5–6	32.82%
	7 or more	6.11%
Age (years)	Less 18	0.00%
	18–24	3.82%
	25–34	16.79%
	35–44	25.19%
	45–54	20.61%
	55–64	16.79%
	More than 64	16.79%

Note: This table presents the average about the social characteristics of farmers in San Miguel, El Salvador; this date presents information about land disponibility, age of farmers, and size of families.

2.7 | Calculation of Indicator Levels

To evaluate the indicators, data were collected through a structured survey. The response options of this instrument were based on national averages published by the MAG, specifically related to yields, labor and other relevant variables. For example, indicator 1, on crop productivity, assesses the land's capacity to produce the highest possible amount of marketable or consumable product in good condition, that is crop yield. For the analysis of this information, the yield per manzana is $= 7000\,m^2$. According to MAG (2019), the national average yield for corn is 67.37 quintals per manzana. In the corresponding survey question, a yield of exactly 67.37 quintals per manzana was assigned a score of 2 points. Yields below this threshold were given 1 point, while yields above 67.37 quintals per manzana received 3 points.

The national data used for comparisons in this study were obtained from official reports published by the MAG of El Salvador through the General Directorate of Agricultural Economics [32]. These reports present the results of annual production cost surveys conducted annually by the technical staff of the Agricultural Statistics Division. These surveys are carried out via direct interviews with producers across the country and collect up-to-date information on inputs, labor, yields and prices. Data collection adheres to standardized and rigorously controlled procedures, including the pre-design of forms, route planning, technical training for field staff, on-site verification and post-processing validation. Furthermore, price standardization is applied, even in cases where inputs have been donated, in order to ensure data comparability.

Both direct costs (e.g., labor, inputs, mechanical work and harvesting) and indirect costs (e.g., administration, contingencies, interest, land rent and water fees) are calculated for each crop based on a standardized unit of agricultural land (one manzana = 7000 m^2). This information not only provides a reliable technical reference but also serves as a critical input for the development of agricultural public policies. Consequently, comparisons with local data from farmers in San Miguel enable the assessment of how effectively these policies are being implemented on the ground.

Once the data were collected, they were exported from QuestionPro in Excel workbook format. The survey responses were then organized by grouping questions according to their the corresponding indicator, and Table 2 shows the questions corresponding to each indicator. The weighted values assigned to each response option were summed to generate an overall score for each farmer.

To validate the results and indicators, an item-total correlation analysis was conducted. This method assesses the extent to which each questionnaire item is associated with the overall scale score, excluding the item in question from the total. This correlation helps identify the individual contribution of each item to the measurement of the overall construct. The correlation is typically calculated using coefficients such as Pearson's, which reflect the strength and direction of the linear association between each item and the total score. High and positive values indicate that an item is consistent with the construct being measured, while low or negative correlations suggest that the item may be irrelevant or confusing, warranting revision or removal. This analysis is essential for ensuring the instrument's quality and for enhancing its validity and reliability [25, 33].

To verify or evaluate the alignment of the questions with the defined sustainability categories, an analysis was conducted by isolating each item and calculating its correlation with each of the sustainability domains. As shown in Table 2, of the items evaluated, two demonstrated a high correlation, 11 showed a moderate correlation, and 10 exhibited a low correlation. For subsequent analyses, only items with a correlation coefficient of 0.30 or higher will be retained.

Subsequently, a maximum–minimum analysis was conducted for the indicators, and three score ranges were established to represent high, medium, and low levels of sustainability. For each level, the simple frequency was calculated to determine the percentage of farmers falling within each category.

2.8 | Ethical Considerations

All participants were informed about the purpose of the study and voluntarily agreed to participate. Informed consent was obtained prior to questionnaire administration, and participants were assured of the confidentiality of their responses. As the study did not involve medical interventions or vulnerable populations, and all data were anonymized, formal approval from an ethics committee was not required in accordance with institutional guidelines.

3 | Results

3.1 | Results of the Statistical Hypothesis Analysis

The mean and standard deviation data were calculated from the data of the individual food groups of the 141 farmers. The results were mean 3.67 and standard deviation 1.80. Using these values, the Z-score was computed, which was then used to draw conclusions from the results.

$$Z = \frac{3.67 - 4}{\frac{1.80}{\sqrt{141}}} = -2.20.$$

Based on this result, the standard normal distribution was used to identify the area corresponding to the obtained data point. The data fell within the rejection region of the null hypothesis. Therefore, the null hypothesis (H_0) was rejected, leading to the conclusion that the basic grain farmers in this study have an individual food diversity score greater than or equal to four food groups.

As shown in Table 2, Hypothesis 2 examines whether basic grain farmers in San Miguel who implement an agricultural production plan differ in their level of economic sustainability from those who do not. The results indicate that both groups, farmers with and without a production plan, exhibit comparable levels of economic sustainability.

3.2 | Current Level of Sustainability of Basic Grain Agriculture

To quantify the percentage of farmers at high, medium, and low levels of sustainability, appropriate scales were applied for each indicator based on the maximum and minimum scores. This allowed for the classification of farmers into each sustainability level and the calculation of the corresponding percentages.

The economic, social, and environmental sustainability levels of basic grain farmers in San Miguel were generally low, indicating vulnerability across all three dimensions. These results highlight the existing limitations in achieving higher sustainability levels among these farmers. The indicators and sustainability levels presented serve as a useful tool for institutions and policymakers to develop policy recommendations that are aligned with the actual conditions faced by farmers.

3.3 | Economic Sustainability

The set of indicators 1 were production plan, actual production costs, crop profitability, production plan and others, as shown in Figure 1, to assess economic sustainability predominantly reflected low levels of sustainability. Most farmers exhibited limited economic autonomy, as evidenced by low profitability. Crop productivity was also generally unsustainable, and none of the farmers employed a production plan for their crops. The findings indicate that, on average, ~69% of basic grain farmers demonstrate low economic sustainability. Hypothesis testing revealed

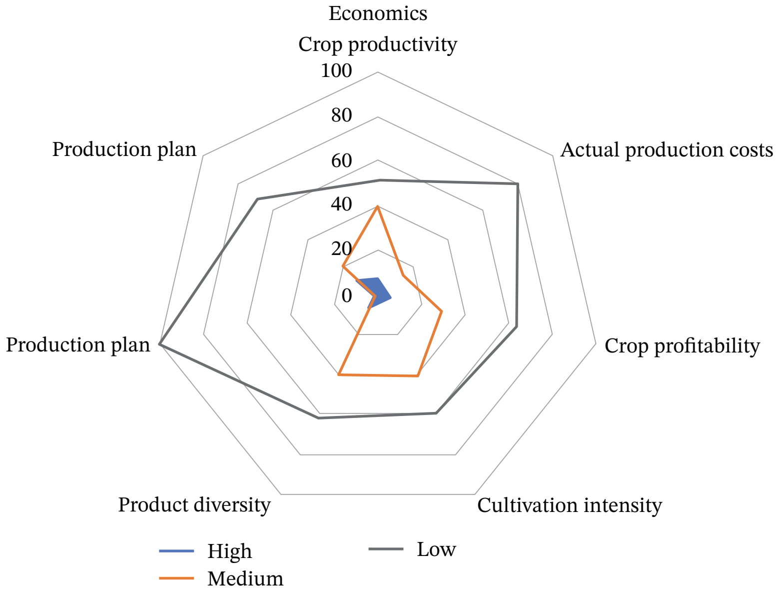

FIGURE 1 | Current levels of economic sustainability of maize farming in San Miguel. The blue, orange, and gray lines represent high, intermediate, and low levels of sustainability, respectively. When most farmers achieve a high level of sustainability, the blue line approaches the outer boundary of the radar chart. Conversely, if the line remains closer to the center, it indicates that maize farming in San Miguel exhibits lower sustainability.

that farmers who price their products based on production costs achieve higher levels of economic sustainability compared to those who do not. This suggests that many farmers, due to various factors, are unable to sell their products at or above production costs.

3.4 | Environmental Sustainability

With respect to the environmental conditions of basic grain farmers of San Miguel, they were found to be in a vulnerable position due to their reliance on seasonal rainfall, as they lacked irrigation systems for their crops, this is evidenced by a low level of water availability, as shown in Figure 2.

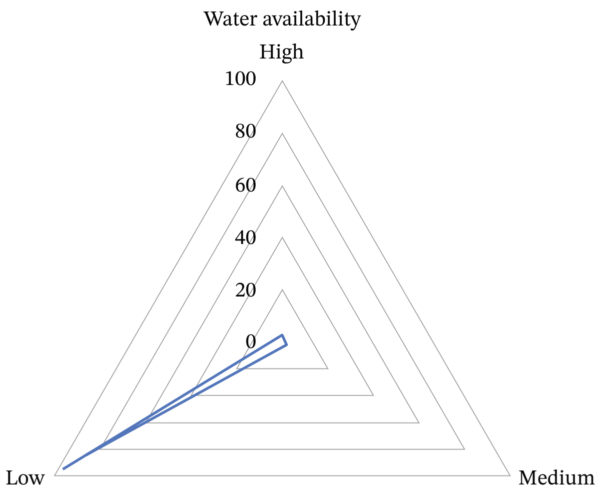

FIGURE 2 | Availability of water for irrigation among basic grain farmers in San Miguel. The figure illustrates that the majority of farmers lack irrigation systems, making them highly dependent on seasonal rainfall and vulnerable to climatic variability.

Another environmental factor assessed was the use of agrochemical active ingredients. A significant majority of farmers (67.38%) reported using paraquat (commercially known as Gramoxone). Additionally, 12.77% used Volaton, another 12.77% used a combination of sulfate and formula, and 7.09% used Folidol. The use of agrochemicals such as Paraquat, Volatón and Folidol represents a critical sustainability concern, as shown in Figure 3, which displays high percentages of substances harmful to both the environment and human health. Research conducted in the Central American region has linked these substances to both acute poisonings and long-term health effects [34]. In addition, their persistence in soils and surface water has been documented, with confirmed risks for local ecosystems [35]. Based on this background, the results obtained in San Miguel—where over 67% of farmers reported the use of highly toxic agrochemicals —highlight an added layer of environmental vulnerability that hinders progress toward sustainability in the region.

3.5 | Social Sustainability

In the social aspect, several indicators of sustainability were considered. Regarding land availability for cultivation, 87.25% of farmers were classified as having a low level of sustainability. Similarly, access to basic services such as water and electricity was also limited, with 76.87% of farmers falling into the low sustainability category. Figure 4 shows that most farmers exhibit low levels across the set of indicators, for example, employment levels were notably low as well: 100% of farmers reported working fewer than 6 months per year in agriculture. Furthermore, 91.49% of farmers lacked access to credit for crop production, and 92.91% did not use machinery in their farming activities. This refers to the limited time allocated to agricultural activities, which is largely influenced by the rainfall patterns in the Dry Corridor, where most agricultural labor is concentrated during the rainy season. However, the absence of alternative income-generating opportunities during the rest of the year also

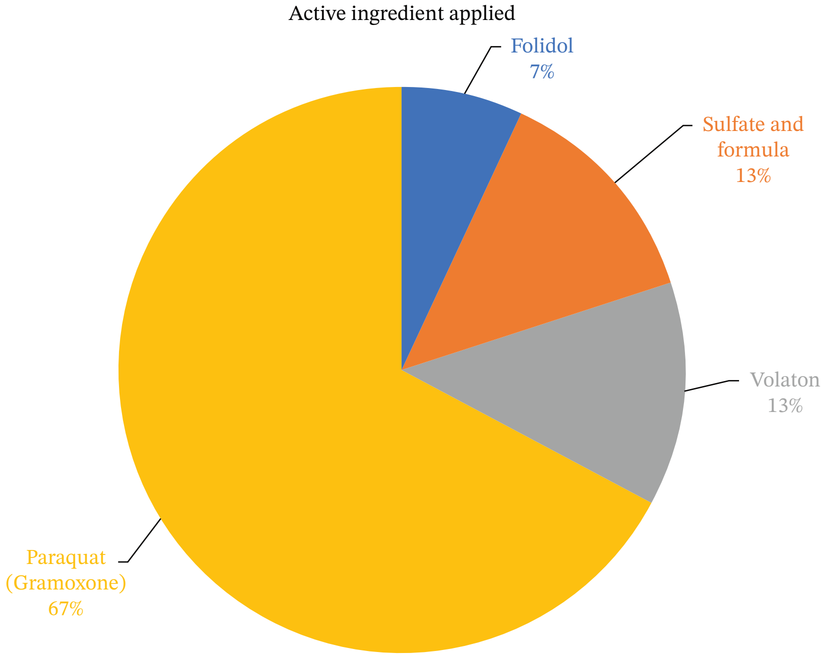

FIGURE 3 | Agrochemicals used by basic grain farmers in San Miguel. This figure presents the distribution of active ingredients applied in crop production. Results show that 67.38% of farmers reported using paraquat (Gramoxone), 12.77% Volaton, 12.77% sulfate and formula, and 7.09% Folidol. The predominance of highly toxic substances such as paraquat highlights significant environmental and public health concerns, emphasizing the need for sustainable alternatives.

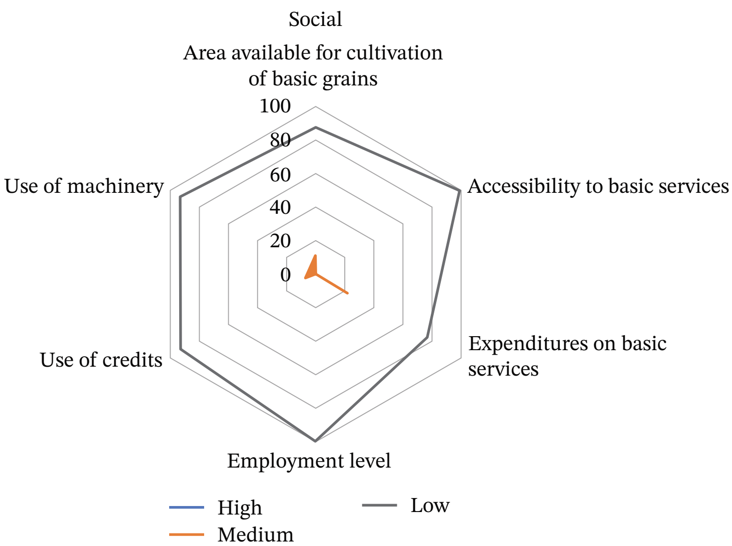

FIGURE 4 | Indicators of social sustainability among basic grain farmers in San Miguel. The results show predominantly low levels of access to essential services such as health care, water, and electricity, as well as limited employment stability. These conditions highlight structural vulnerabilities that constrain social sustainability in the study area.

highlights a structural condition of underemployment in the region. Dietary diversity was also assessed. Statistically, it was found that the basic grain farmers included in this study achieved an individual dietary diversity score of four or more food groups.

Overall, the results reveal significant shortcomings in the social dimension of sustainability, particularly in relation to livelihoods, access to resources, and production capacity. Combined with the economic and environmental outcomes, these findings indicate a systemic vulnerability within the evaluated agricultural system, which is explored in greater detail in the Discussion section.

4 | Discussion

The results obtained through the applied methodology reveal marked differences in sustainability performance across the economic, environmental and social dimensions of staple grain production in San Miguel. These findings indicate systemic vulnerabilities that constrain production capacity, limit access to essential resources, and hinder the adoption of improved agricultural practices, factors that are critical for sustainability in smallholder farming systems. To facilitate interpretation, this section discusses the methodological strengths and limitations of the approach and compares the outcomes with those reported in other sustainability assessment studies.

4.1 | Strengths and Weaknesses of the Methodology

The methodology employed in this study draws upon approaches used in previous research, such as the work of Kinderité [30], which assessed the sustainability of small and medium-sized enterprises using a set of sustainability indicators. Recognizing the challenges of quantitatively capturing certain aspects of sustainability, this work developed both qualitative and quantitative indicators. The indicators were selected and subsequently validated through consultation with sustainability experts. Similarly, Moreno and Fidélis [31], in their research on local sustainability indicators in Portugal, utilized both qualitative and quantitative data collection methods, including a survey of local councils to identify available sustainable development indicators. Additionally, they conducted case studies of selected municipalities, based on the survey results and specific criteria used to guide the selection process.

In this study conducted in San Miguel, the selection of sustainability indicators was guided by methodologies from previous research and emphasized the active participation of stakeholders involved in the basic grains production process. Farmers contributed to the study by responding to the data collection instruments and participating in a focus group comprising key actors in the agricultural value chain. This participatory approach was essential for validating the proposed indicators [36].

For studies that consider the application of this methodology to measure sustainability, it is recommended to first develop a preliminary set of indicators to be presented to the stakeholders. Employing a community-based diagnostic approach is also suggested to explore sustainability issues and review the value ranges of each indicator.

Since the methodology was applied specifically to basic grain producers in San Miguel (El Salvador), the results are not directly comparable to data from other countries with different economic, social and environmental contexts. However, this contextual specificity can be viewed as a strength, as it ensures that the indicators are tailored to the local reality. This localized design supports the formulation of policy measures that are more relevant and effective for the San Miguel region.

Analysis of the data collected from farmers revealed that the majority have not completed education beyond the sixth grade. Additionally, most participants were between 35 and 64 years of age. Economic constraints were identified as a major barrier to adopting new technologies, which in turn affects income generation and the ability to invest in the tools required to implement production plans. It is acknowledged that appropriate technologies can mitigate environmental impacts [37]. In this regard, representatives from Fundación Campo noted that the organization is making significant efforts to transfer knowledge to farmers through the use of ICTs. Nevertheless, there remains a lack of in-depth information on the application of agricultural technologies in the region of San Miguel.

With respect to entrepreneurship, the study found that most farmers do not have year-round employment, with work largely limited to the rainy season harvest. Moreover, there is growing concern that younger generations show little interest in agricultural work, exacerbating challenges related to employment and economic contribution in rural areas [38]. Small-scale agricultural producers face substantial challenges in sustaining their businesses, especially in a market dominated by large-scale producers. These producers often struggle to access competitive prices, highlighting the urgent need for training in business negotiation and market access. In terms of agricultural planning, it is crucial to develop production plans aimed at maximizing land productivity and anticipating the material and human resources required to achieve production goals. In recent years, global land-use efficiency has increased, with higher yields being achieved without expanding agricultural land [39]. Achieving similar outcomes in San Miguel will require the diversification of crops and the implementation of crop rotation practices, which also contribute to improved soil fertility and overall productivity.

4.2 | Are the Results of This Methodology Related to Other Methodologies?

The literature review confirms a range of previous research efforts that have assessed sustainability using indicator-based approaches, as shown in Table 1. In this study, the development of indicators was informed by the experiences of farmers, market actors, nongovernmental organizations and data from governmental sources. The selected indicators encompass three core dimensions of sustainability: environmental (e.g., water accessibility and quantity of active ingredients applied), social (e.g., food diversity, access to basic services, education and employability), and economic (e.g., productivity and profitability, among others). The sustainability indicators identified in this study reflect context-specific challenges and dynamics typical of developing countries, thereby offering a localized lens for understanding sustainability in agricultural systems.

It is well established that one of the key challenges facing these countries is achieving economic sustainability to ensure food diversity and address the diverse needs of farming families. Farmers have emphasized the importance of economic cooperation through various development projects that provide them with greater financial stability. In this sense, these indicators reflect a call from the farmers for the implementation of agricultural sustainability policies aimed at improving the economic, social, and environmental conditions for their productive activities.

The effective application of the chosen methodology enabled an assessment of the local conditions of farmers across economic, social, and environmental dimensions. Although the research team was involved in moderating the focus groups and developing the research instruments, raising the possibility of expert-driven indicator selection, the methodology employed allows for the extraction of key sustainability elements directly from the experiences of the participants. As in Bossel [40], this study established sustainability indicators through an integrated management approach, incorporating input from the community, cooperatives, government agencies, and academic institutions. The involvement of these stakeholders facilitates the collection of relevant data to assess sustainability levels. Similarly, both this study and Bossel's work generated a set of parameters designed to collect information from farmers for calculating sustainability indicators.

Currently, the agricultural sector faces a shortage of young labor. In this study, the majority of respondents were between 35 and 54 years old (46%), followed by those over 55 (34%). In contrast, only 4% of respondents were in the 18 – 24 age group. Consistent with the findings of Oluwatoyin et al. [41], agriculture is often perceived by youth as an unattractive economic activity, largely due to barriers such as lack of access to land and limited targeted social support for farmers. This perception contributes to the marginalization of agriculture as a viable livelihood, weakening its role in local development and food security [39].

In rural areas of Central America, agricultural activities are typically family based and diversified, often including various subsistence crops in addition to the commercial production of basic grains [42]. Culturally, it is commonly believed that families tend to have more than two children to ensure sufficient labor support for farm work. In our study, 45.80% of farmers reported having family units consisting of 3 – 4 members, while 38.93% had households with more than five members. A similar pattern was observed in the study by Álvarez-Cuello and De Nóbrega [43] in Venezuela, which provided an agricultural and demographic characterization of two farmer groups located near urban areas, reporting an average household size of 4.5 members.

In El Salvador, 23.6% of children and adolescents are not enrolled in school, a figure that contrasts sharply with the 2% rate reported for North America and Western Europe [44]. This finding aligns with the results of the present study, in which 26.72% of respondents reported having no formal education.

Regarding crop types, the majority of farmers in San Miguel grow corn, accounting for 72% of agricultural production. Corn is a basic grain that plays a vital role in sustaining agricultural dynamics in El Salvador. It occupies a larger proportion of cultivated land compared to other crops, and its yield has shown significant improvement over time. By 2013, corn productivity reached 3 tons per hectare—representing a 58% increase compared to yields from the 1970s [45].

The Technical Secretariat for Women of the Council of Women's Ministers of Central America and the Dominican Republic [46] highlights the tendency to attribute agricultural work to men, as it is perceived to require greater physical effort. This gender-based perception is reflected in the findings of our study, which show that the majority of farmers are men. These data further suggest that women are often relegated to unpaid domestic labor.

This study advances existing practice by adapting a set of sustainability indicators, derived from international frameworks and specialized literature, to the socioeconomic and environmental realities of basic grain farmers in San Miguel, El Salvador. Unlike previous approaches that apply indicators in a generic way, the indicators in this research were contextualized through the integration of national cost-of-production data from the Ministry of Agriculture, field survey results, and statistical validation. This methodological strategy allowed for the operationalization of sustainability measurement in a more precise and context-specific manner, ensuring that the indicators reflect the conditions of the Central American Dry Corridor. Although global indicators, such as biodiversity or greenhouse gas emissions, could not be directly measured due to data limitations, proxy variables, such as crop diversity, agrochemical use, and cropping intensity, were employed to indirectly capture these dimensions. This combination of rigor and contextual adaptation offers a replicable framework for sustainability assessment in other regions with similar information constraints, thus strengthening both the academic and policy relevance of indicator-based methodologies.

5 | Conclusions

This study is the first attempt to measure the sustainability of basic grain farmers in San Miguel. Based on a comprehensive literature review, a set of indicators was developed, including those identified as critical for assessing the various dimensions of sustainability. The methodological approach of this research is marked by several strengths, particularly the incorporation of data collected from farmers, nongovernmental organizations, and market actors to inform the construction of indicators. In this study, some indicators were constructed from two or more variables collected in the field (e.g., costs and sales prices to estimate profitability, or type of machinery and access to credit to approximate production capacity). This approach does not compromise the specificity of the indicators; rather, it reflects the multidimensional nature of sustainability, where several measurable elements must be combined to capture a single construct. The use of composite indicators has been recognized in sustainability assessments as a valid strategy to integrate interrelated dimensions and producing more comprehensive evaluations [47].

Farmers in San Miguel, as in the rest of El Salvador, are often analyzed using a uniform approach that overlooks the region's specific climatic conditions. However, local farmers reported noticeable changes in climate patterns, which have adversely affected their crop yields. Participation in international cooperation projects could provide farmers with access to financial resources, thereby improving their quality of life through the diversification and/or increased efficiency of agricultural production. For future research conducted in El Salvador or other countries, the sustainability indicators and methodology presented in this study could be validated and adapted to local contexts.

Author Contributions

Nurian Y. Luna-Laínez conducted the field study and analyzed the results obtained. Jorge Poveda supervised all research. Nurian Y. Luna-Laínez and Jorge Poveda designed the research, wrote the manuscript, and made revisions.

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Disclosure

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available upon request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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