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Sustainability assessment of mixed farming systems among farmer field school participants

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ABSTRACT

Objective: To assess the sustainability of mixed farming systems among producers participating in Farmer Field Schools in ten municipalities of Zacatecas, Mexico, and identify strengths and areas needing intervention.

Design/Methodology/Approach: A structured, participatory survey was conducted with 58 producers. The survey covered five sustainability dimensions: economic, environmental, social, technical-productive, and climate resilience. Data analysis included descriptive statistics, principal component analysis (PCA), and ordinal logistic regression.

Results: The findings indicated that 50% of producers reached a medium sustainability level, 36% high, and 14% low. The environmental dimension scored the highest, while technical-productive and climate resilience showed the greatest weaknesses. Agricultural surface area was the only significant predictor of sustainability ($p<0.05$), suggesting that land access supports adopting agroecological practices.

Limitations/Implications of the study: The cross-sectional design restricts the ability to track changes over time. Future longitudinal studies are recommended to evaluate the long-term effects of technical assistance and training programs over time.

Findings/Conclusions: Access to productive resources and strengthening technical and organizational capacity are crucial for moving toward resilient, sustainable mixed farming systems in semi-arid areas.

Keywords: Agroecology; Farmer Field Schools; climate resilience; mixed farming systems; rural sustainability.

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INTRODUCTION

Mixed farming systems, characterized by the integration of crop and livestock activities within the same production unit, represent a traditional and resilient strategy used by many rural producers in semi-arid regions like Zacatecas, Mexico. These systems enable risk diversification, efficient use of available resources (such as water, soil, and organic residues), and income generation from multiple sources, which is crucial for the food security of smallholder families (FAO, 2001; Herrero *et al.*, 2010). In Latin America, crop-livestock integration has been shown to enhance the overall agroecological performance of farming systems (Stark *et al.*, 2018).

Despite these benefits, mixed systems face multiple challenges that threaten their long-term sustainability. Increasing climate variability, natural resource degradation, rising production costs, and limited access to technical and extension services have jeopardized their economic, environmental, and social viability (Altieri & Nicholls, 2017; Gliessman, 2015). Given these challenges, there is a need for participatory approaches that strengthen farmers' technical, organizational, and adaptive capacities while promoting sustainable production practices. Farmer Field Schools (FFS) represent one such approach, providing a platform for hands-on learning and peer-to-peer exchange tailored to local agroecological conditions. Assessing the sustainability of mixed farming systems among FFS participants can therefore provide valuable insights into their effectiveness and identify priority areas for intervention. In this context, it is important to strengthen producers' abilities to handle these challenges through participatory learning and local adaptation processes.

Farmer Field Schools are a training approach centered on practical learning, knowledge sharing, and collective problem-solving. Their implementation has shown positive effects in strengthening technical and organizational skills and promoting the adoption of sustainable practices in various countries around the world (Braun *et al.*, 2006; van den Berg *et al.*, 2021). In Mexico, FFS have been integrated into public rural development programs; however, there is a lack of systematic evaluations of their impact on the sustainability of production systems, especially in mixed systems of semi-arid regions.

Sustainability, defined as the ability of productive systems to maintain their function over time without depleting natural resources or harming the well-being of future generations, must be evaluated holistically. This includes considering economic, environmental, social, technical-productive, and climate resilience aspects (Pretty, 2008). Assessing these aspects helps identify opportunities, guide improvement actions, and generate evidence to support decision-making at both producer and public policy levels.

This study evaluated the sustainability of mixed farming systems among producers involved in Farmer Field Schools across ten municipalities in Zacatecas. Using a structured survey with a participatory approach, the five dimensions of sustainability —economic, environmental, social, technical-productive, and climatic— were thoroughly analyzed, highlighting strengths and key areas for improvement. The findings serve as a foundation for developing technical assistance strategies that encourage sustainable practices tailored to rural settings. Therefore, the objective of this study was to assess the sustainability of mixed farming systems among Farmer Field School participants in Zacatecas, Mexico, and to identify their main strengths and areas requiring intervention.

MATERIALS AND METHODS

Study type and study area

A cross-sectional, quantitative study was conducted in the first quarter of 2025 in the state of Zacatecas, Mexico. The influence area included ten municipalities selected for their participation in agricultural training programs through Farmer Field Schools: Jerez, Valparaíso, Zacatecas, Villanueva, Villa de Cos, Fresnillo, Vetagrande, General Enrique Estrada, Susticacán, and Tepetongo. These municipalities are situated in steppe dry climate zones and share similar agroecological characteristics (INEGI, 2022).

Population and sample

The target population consisted of producers actively participating in Farmer Field Schools promoted by the Secretariat of Agriculture and Rural Development (SADER, 2023). A non-probabilistic convenience sampling method was used, selecting 58 producers who voluntarily attended training sessions during which the survey was administered. The non-probabilistic sampling limits the generalization of results to the broader population of mixed farming producers in Zacatecas; however, it provides relevant insights into the targeted group participating in Farmer Field Schools.

Assessment instrument

A structured survey specifically designed for this study was used, based on principles of sustainable agriculture and participatory evaluation criteria (Pretty, 2008; Gliessman, 2015). The survey included a series of direct sociocultural questions aimed at characterizing the producers' profiles. These questions addressed aspects such as gender, age, education level, type of producer (family or commercial), experience in the production system, livestock type, land tenure, and available surface area. The survey instrument was validated through expert review and a pilot test with 10 producers to ensure clarity and relevance.

Additionally, the instrument included 26 dichotomous-response items (Yes=1, No=0) spread across five sustainability dimensions: economic (5 items), environmental (6 items), social (5 items), technical-productive (5 items), and climate resilience (5 items). Each dimension featured specific questions aimed at capturing producers' practices, resources, and perceptions. For example, the economic dimension asked about income diversification, access to credit, and marketing; the social dimension covered participation in organizations, generational renewal, and perceptions of well-being; the environmental dimension examined the use of agrochemicals, soil conservation, and waste management; the technical-productive dimension focused on record-keeping, management planning, and crop or forage rotation; finally, the climate adaptation dimension considered practices like adjusting agricultural or livestock calendars and implementing adaptive technologies.

The maximum score a producer could achieve was 26 points. Based on the total score, three sustainability levels were defined: low (0-10 points), medium (11-17 points), and high (18-26 points), using criteria adapted from previous agroecological assessment models (Astier *et al.*, 2012). This approach allowed for capturing both observable practices and decision-making processes relevant to the sustainable performance of mixed systems.

All questions were designed around technical criteria for good agricultural and livestock practices, as well as principles of agroecology and rural sustainability. The survey was administered directly by researchers during field sessions to ensure participants' understanding. All participants provided informed consent prior to the survey. The study adhered to ethical research principles.

Data processing and statistical analysis

A descriptive analysis of frequencies, means, and standard deviations was performed for both quantitative and categorical variables. Additionally, bivariate analyses were conducted to examine associations between sociodemographic variables (gender, education level, livestock type) and sustainability levels using the Chi-square test (χ^2). Statistical analyses were performed using SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA), with a significance level of $\alpha=0.05$.

Multivariate principal component analysis (PCA) was used to reduce the dimensionality of the five sustainability dimensions and visualize clustering patterns among producers. The first two principal components explained 66.3% of the total variance. Ordinal logistic regression was performed to identify variables that predict sustainability levels (low, medium, high). Variables included age, gender, education, livestock type, agricultural surface area, technical support, and climate change adaptations. The dependent variable was ordered, and the model was estimated using maximum likelihood estimation.

RESULTS AND DISCUSSION

Sociocultural and productive profile

The average age of the surveyed producers was 45.8 years, ranging from 18 to 83 years. Disaggregated by gender, men had an average age of 46.2 years (range: 18 to 83 years), while women averaged 43.2 years (range: 22 to 70 years). These data reflect the active participation of an adult population, mostly within productive age, in the Farmer Field Schools of mixed agricultural systems. The producers' age may influence the sustainability of production systems both positively and negatively. An older average age may be linked to greater experience in agricultural management, while a younger age is often associated with higher openness to technological change (Fertő *et al.*, 2025). Generational renewal in agriculture is a global challenge, constrained by factors such as low motivation among young people and limited access to land (Borda *et al.*, 2023). The slight age difference between men and women may relate to different paths of entry into farming, as women often become more actively involved at later stages, for instance, as household heads or in response to male migration (FAO, 2017). Evidence suggests that younger farmers, particularly women, may show greater adoption of sustainable and innovative practices (Fertő *et al.*, 2025). This finding highlights the importance of designing training strategies with a generational and gender perspective that recognizes and values age diversity as a strength for rural territorial sustainability.

The analysis showed that 72% of the producers were men and 28% women, highlighting a notable level of women's participation in Farmer Field Schools. Despite their significant involvement, women in agriculture across Latin America have historically been under-represented and face barriers in access to resources and education, often accounting for only about 20% of the agricultural labor force and encountering disparities in land ownership and technology access (Gibbons *et al.*, 2022). Regarding education, most respondents had completed primary (39%) and secondary (29%) education, while only 8% had achieved professional or higher education levels. Those proportions mirror broader trends in rural areas, where limited opportunities for technical and higher education —especially for women— constrain their advancement (FAO, 2011). Additionally, 24% reported having technical or vocational training. Concerning the type of producer, 65% identified as family producers and 35% as commercial producers. This aligns with the predominance of family farming in the region: globally, family farms constitute over 98% of agricultural establishments and manage more than half of the agricultural land, often operating under small- or medium-sized production structures with strong family foundations (Graeub *et al.*, 2016). These figures indicate that most participants are involved in small- or medium-sized production structures with a strong family foundation.

The analysis of livestock types showed diversity among participating producers. The most common category was cattle (61%), followed by those combining cattle with small ruminants (sheep and goats) at 31%. The remaining included specialized systems like sheep, beekeeping, pigs, or combinations of these. These results reflect a widespread trend toward diversified livestock systems, a typical trait of family-based mixed systems in rural areas, which is crucial for the sustainability of production units in regions with high climatic and economic variability (Altieri & Nicholls, 2012; FAO, 2018). Recent studies indicate that functional interactions among components of multi-species systems enhance the technical and environmental performance of production units (Steinmetz *et al.*, 2021). The diversification observed in these production systems aligns with experiences reported in other parts of Latin America, where crop-livestock integration has shown benefits for productivity, resilience, and efficient resource use (Stark *et al.*, 2018).

This trend toward diversification aligns with the agroecological approach of resilient systems, where functional biodiversity reduces risks, enhances nutrient cycling, and provides complementary income for rural households. Agroecological principles emphasize diversity, synergy, and economic diversification as core strategies for sustainable transformation (Wezel *et al.*, 2020). Additionally, the presence of minor species such as bees, pigs, or poultry, although less reported, reflects a multifunctional view of the production system that combines economic, food security, and ecological goals. Agricultural diversification has been shown to increase long-term financial profitability, biodiversity, and ecosystem services —sometimes by over twenty-fold— while maintaining stable yields (Raveloaritiana & Wanger, 2024). The high number of producers who rely on cattle as their main species may also be influenced by cultural factors, access to basic infrastructure, and market demand. However, cattle production requires more feed, water, and health management, presenting a challenge to overall sustainability if not supported by training and technical assistance.

The average area dedicated to livestock activities among surveyed producers was 30.8 hectares, with a range from small backyard systems (0 ha) to large operations covering up to 300 ha. This variability highlights the coexistence of family production units with limited land access and larger systems in rural areas. The wide variation in livestock area reflects the structural diversity of mixed agricultural systems in Zacatecas. Small-scale units, including backyard setups, are common in peri-urban or mountainous regions and are often linked to subsistence economies, self-consumption, and the multifunctionality of rural households (Altieri & Toledo, 2011). In contrast, extensive units exceeding 100 hectares make up a smaller yet significant portion that may have greater capacity to invest in technology, infrastructure, and strategic forage management. This duality indicates the need for tailored policies that recognize the specific needs of both groups: some require technical assistance and access to basic resources, while others could benefit from certification schemes, differentiated marketing, and advanced training to move toward sustainable livestock models.

Sustainability level of mixed production systems

The assessment of sustainability levels in the studied mixed agricultural systems showed that 50% of producers were categorized as medium, 36% as high, and 14% as low. This suggests that, although many producers have adopted sustainable practices, there are still technical and structural gaps in different parts of the production system.

When analyzing the average scores by dimension, the environmental dimension had the highest mean value (3.83±1.51), followed by the economic (3.52±1.13) and social (3.50± 1.10) dimensions. In contrast, the technical-productive (2.52±1.42) and climate resilience (2.36±1.37) dimensions scored the lowest, indicating weaknesses in livestock planning, the use of appropriate technologies, and adaptation strategies for extreme climatic events.

The economic dimension had an average score of 3.52 points, with scores ranging from 0 to 5, while the social dimension reached the full 5 points with a similar average of 3.50. The technical-productive dimension, however, showed more variability among producers, likely due to differences in access to resources and basic infrastructure. Climate resilience performed particularly poorly, highlighting an urgent need to enhance capacities in drought management, water harvesting, and climate change adaptation.

These results clearly highlight areas for improvement that should be tackled through technical support strategies, building local capacities, and tailored policy support for mixed agricultural systems in the region.

Figure 1 displays the distribution of the sustainability level achieved by producers based on their gender. It shows that both men and women are present across all three levels (low, medium, and high); however, women tend to be more concentrated in the medium and high levels, while the low level is more commonly associated with men.

This pattern indicates a potential positive impact of women's involvement in training and organizational activities within the Farmer Field Schools. Several studies have shown that rural women, when actively engaged in resource management, tend to adopt agroecological practices more effectively, especially those related to water efficiency, waste management, and organizing productive activities at the family level (Altieri & Toledo, 2011; Van den Berg *et al.*, 2020).

Tabla 1. Descriptive statistics by sustainability dimension

Dimension	Media	DE	Minimum	Maximum
Economic	3.52	1.13	0	5
Environmental	3.83	1.51	0	6
Social	3.5	1.10	1	5
Technical-productive	2.52	1.42	0	5
Climate resilience	2.36	1.37	0	5

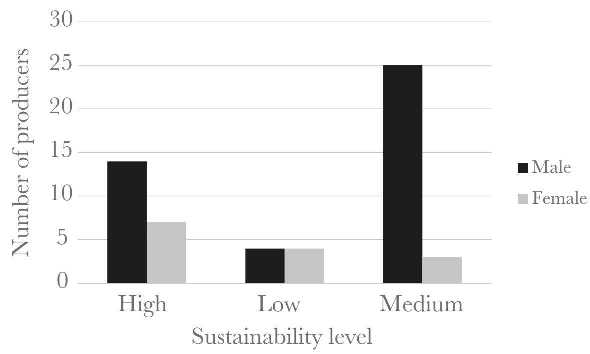

Figure 1. Sustainability level by gender of mixed farming system producers.

Furthermore, the observed trend aligns with research recognizing the strategic role of women as agents of change in diverse agricultural systems, especially when they participate in collective learning spaces and technical training. Their holistic approach to production —which combines economic, social, and environmental factors— may explain the improved performance in sustainability indicators.

Although the sample size does not allow for establishing causal relationships, these findings emphasize the importance of promoting greater inclusion and empowerment of women in rural extension programs, recognizing their potential to contribute to more sustainable and resilient systems.

Figure 2 illustrates the relationship between the producers' education level and the sustainability level achieved in their production systems. A positive trend is evident: the higher the education level, the larger the proportion of producers in medium and high sustainability categories. Conversely, lower sustainability levels tend to be concentrated among producers with only basic education or no formal schooling.

This finding aligns with previous studies that identify human capital as a crucial factor in adopting innovations, acquiring technical knowledge, and adapting to adverse conditions (Pretty, 2008; Astier *et al.*, 2012). Higher education levels improve access to, understanding

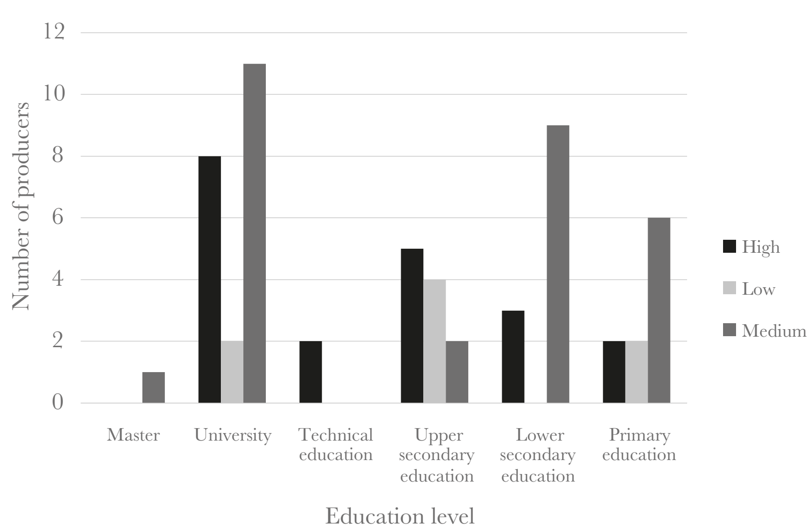

Figure 2. Sustainability level by education level of the producers.

of, and application of concepts related to good agricultural practices, technical planning, and climate adaptation strategies.

Furthermore, producers with higher levels of education often have better access to information, support networks, and effective management tools, which leads to more informed and efficient decisions. In the context of Farmer Field Schools, this may indicate a greater willingness to participate actively in training sessions and a better understanding of the content presented.

These results emphasize the importance of creating tailored training strategies that consider the existing educational gaps in rural areas. Modifying teaching methods to different levels of understanding can help reduce disparities in adopting sustainable practices and boost the effectiveness of interventions in communities with limited access to formal education.

Multivariate analisis

Figure 3 presents the Principal Component Analysis (PCA) ordination of the production units, showing an overall separation among sustainability levels (high, medium, and low) across the first two components.

Logistic regression model

The model showed that agricultural land area was the only statistically significant predictor variable ($p<0.05$), with a positive coefficient indicating that larger land areas increase the likelihood that the producer would be classified at a higher level of sustainability. This could be due to greater resource availability, allowing for the implementation of agroecological practices, crop diversification, or access to financing. The goodness-of-fit statistics indicated that the model had a McFadden's pseudo-R^2 of 0.21 and an Akaike Information Criterion (AIC) value of 154.67, suggesting an acceptable fit and explanatory power for the data.

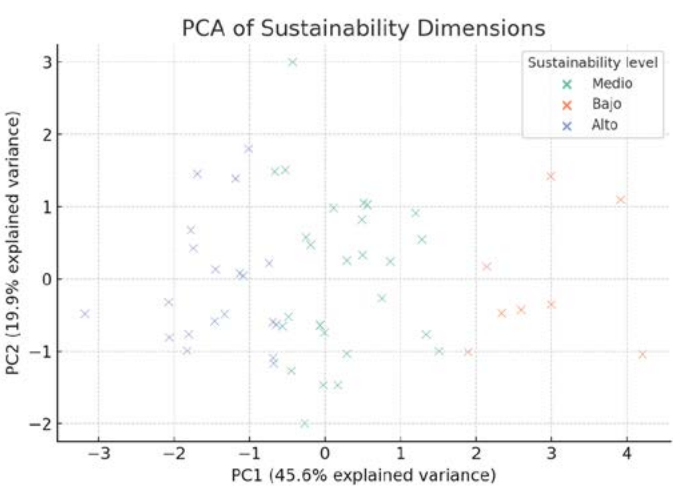

Figure 3. Principal Component Analysis (PCA) of sustainability dimensions, showing the distribution of production units according to sustainability level (high, medium, low). The first two components explain 45.6% (PC1) and 19.9% (PC2) of the total variance.

Although variables such as education level, technical support, and climate change adaptations were not statistically significant, their coefficients were positive, indicating a potential favorable link with sustainability. These findings align with previous research emphasizing the importance of human capital and access to extension services in supporting the shift toward sustainable systems.

Producer age and livestock type did not have significant effects, indicating that other structural and contextual factors might play a more crucial role in determining the sustainability level of mixed-system producers.

The findings of this study emphasize the complexity of the factors affecting the sustainability of mixed farming systems in rural areas. The importance of agricultural land size aligns with previous studies showing that access to larger land parcels enables farmers to diversify crops, adopt good agricultural practices, and implement more sustainable technologies (Astier *et al.*, 2012; Altieri *et al.*, 2015).

On the other hand, although variables such as education level, technical assistance, and climate change adaptations were not statistically significant, their positive effects support the literature highlighting the role of human capital and technical support in enhancing resilience and sustainability in rural systems (Pretty, 2008; Gliessman, 2014).

Despite their theoretical relevance, variables such as education level and climate change adaptation practices were not statistically significant, possibly due to limited sample size or heterogeneity in their implementation across producers.

The lack of significance of the "livestock type" variable may stem from the high diversity of species and management practices among the surveyed producers. Similarly, producer age —usually linked to experience— did not clearly influence sustainability, indicating that other institutional or market factors might be affecting its impact. Several studies have demonstrated that diversification in mixed systems not only enhances environmental resilience but also boosts food production and improves system performance. At the farm level, effectively integrating crops and livestock has been shown to improve the balance between productivity and sustainability (Puech & Stark, 2023).

These results indicate that strategies to improve the sustainability of mixed systems should focus on both increasing access to productive resources and enhancing the technical and organizational skills of producers. Additionally, they highlight the importance of further analyzing contextual factors that either hinder or support the shift toward more resilient and sustainable systems.

Tabla 2. Results of the ordinal logistic regression model

Variable	Coefficient	p-value	Significance
Farmer's age	−0.034	0.158	Not significant
Sex	1.004	0.321	Not significant
Education level	0.195	0.380	Not significant
Agricultural área (ha)	0.052	0.038	Significant ($p<0.05$)
Type of livestock	−0.013	0.906	Not significant
Climate change adaptation practices	0.644	0.477	Not significant
Technical assitance for adaptation	0.656	0.382	Not significant

CONCLUSIONS

This study offers a detailed analysis of the sustainability of mixed farming systems in Zacatecas, Mexico, based on a structured survey of producers involved in Farmer Field Schools. Agricultural land area emerged as the most significant positive factor influencing sustainability, emphasizing the key role of access to productive resources in rural areas. Although variables like education level, technical assistance, and climate adaptation strategies were not statistically significant, their positive trends suggest that they should be considered in future efforts.

These findings can inform public policies focused on strengthening rural extension services, technical assistance, and agricultural resource management, especially for producers participating in training programs like Farmer Field Schools. Additionally, longitudinal studies are advised to track the evolution of sustainability over time and evaluate the effects of different intervention strategies.

The results of this study can be used to develop effective support models and training strategies customized to local contexts, helping to promote a sustainable and resilient transition of mixed farming systems. These findings are relevant not only for Zacatecas but also for other semi-arid regions in Latin America facing similar constraints, and can guide targeted interventions to strengthen mixed farming systems.

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