SUSTAINABILITY OF MAIZE CULTIVATION IN SOUTHERN VERACRUZ, MEXICO †

[SUSTENTABILIDAD DEL CULTIVO DE MAÍZ EN EL SUR DE VERACRUZ, MÉXICO]

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SUMMARY

Background. Currently, sustainable management of production systems is the key to the development of agriculture in Mexico. **Objective**. To analyze the sustainability of agricultural practices carried out by maize producers in the ejido of San Bartolo, municipality of Acayucan, Veracruz, Mexico. **Methodology**. The analysis method of this research was mixed, and the instrument was the interview, the information was processed in the Dyane program, and the sustainability indicators were developed from three transversal axes (social, economic and productive). The data were analyzed using Spearman's R correlation. **Results**. The data showed low sustainability values in the three transversal axes (ranging from 25 to 35%), although the profitability was 1.05, which is very low. Likewise, the correlation analysis indicated that competitiveness may be compromised, since most of the income in the area corresponded to social support, without encouraging productivity, coupled with inefficient marketing channels. Lack of knowledge of technological packages for corn crop management leads to inadequate fertilization and incorrect use of agrochemicals, increasing production costs and affecting yield, crop profitability and the environment. **Implications**. In future research it would be prudent to expand the study to analyze the perspective of decision makers, in order to generate public policies in favor of economic and productive sustainability. **Conclusion**. The sustainability analysis indicated that the agricultural practices carried out by the producers of San Bartolo were very low in the productive (0.31), social (0.35) and economic (0.25) axes, therefore, it is recommended to increase performance through technical advice and the generation of sustainable and profitable production strategies.
Key words: monoculture; agricultural practices; rural development.

RESUMEN

Antecedentes. Actualmente, el manejo sustentable de los sistemas de producción es la clave para desarrollo de la agricultura en México. **Objetivo**. Analizar la sustentabilidad de las prácticas agrícolas que realizan los productores de maíz en el ejido de San Bartolo, municipio de Acayucan, Veracruz, México. **Metodología**. El método de análisis de la presente investigación fue de tipo mixto y el instrumento fue la entrevista, la información fue procesada en el programa Dyane, y los indicadores de sustentabilidad fueron desarrollados a partir de tres ejes transversales (social, económico y productivo). Se analizaron los datos mediante la correlación R de Spearman. **Resultados**. Los datos mostraron valores bajos de sustentabilidad en los tres ejes transversales (que van de 25 a 35%), aunque la rentabilidad fue de 1.05, es muy baja. Así mismo, los análisis de correlaciones indicaron que la competitividad puede estar comprometida,

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ya que la mayor parte de los ingresos de la zona correspondieron a apoyos sociales, sin incentivar la productividad, aunado a los ineficientes canales de comercialización. La falta de conocimiento de los paquetes tecnológicos para el manejo del cultivo de maíz trae consigo, la fertilización inadecuada y el uso incorrecto de agroquímicos, incrementando los costos de producción, y afectando el rendimiento, la rentabilidad del cultivo y el medio ambiente. **Implicaciones**. En futuras investigaciones sería prudente ampliar el estudio para analizar la perspectiva de los tomadores de decisiones, a fin de generar políticas públicas en favor de sustentabilidad económica y productiva. **Conclusión**. El análisis de sostenibilidad indicó que las prácticas agrícolas realizadas por los productores de San Bartolo fueron muy bajas en los ejes productivo (0.31), social (0.35) y económico (0.25), por lo que se recomienda incrementar el rendimiento a través de la asesoría técnica y la generación de estrategias de producción sostenibles y rentables.
Palabras clave: monocultivo; alternativa productiva; desarrollo agropecuario.

INTRODUCTION

The agricultural sector plays a crucial role in meeting the growing global demand for food and other agricultural products; however, ensuring the sustainability of agricultural practices is a major challenge to ensure food security (Landini and Beramendi, 2020; Tkemaladze, 2025). The concept of agricultural sustainability has become a central focus for policymakers and researchers, as it encompasses various aspects, including environmental, economic, and social considerations (Pretty, 2008).

One of the key aspects of sustainable agriculture is the efficient management of natural resources, such as soil, water, and biodiversity (Magrini and Giambona, 2022). The extensive use of fertilizers, pesticides, and water in conventional agricultural practices has led to significant environmental impacts, including soil degradation, water pollution, and loss of biodiversity (Kumawat *et al*., 2021). To address these concerns, researchers and practitioners have explored the development of more environmentally friendly agricultural techniques that can maintain or even enhance productivity while minimizing harm to the environment (Ghasemzadeh, 2012).

Organic and conservation agriculture have emerged as promising approaches to promote ecosystem multifunctionality and enhance the sustainability of agricultural systems (Wittwer *et al*., 2021; Cozim-Melges *et al*., 2024). These approaches aim to improve soil fertility and reduce the reliance on synthetic inputs by incorporating natural and organic materials, such as compost and cover crops, into the farming practices (Lampridi *et al*., 2019).

Agricultural sustainability also encompasses economic and social dimensions. From an economic perspective, sustainable agriculture should provide farmers with reliable and adequate income, ensuring the long-term viability of their operations (Lampridi *et al*., 2019). Additionally, sustainable agriculture should contribute to the overall economic development of rural communities and the broader society (Ayala and Hernández, 2024). The social dimension of agricultural sustainability involves ensuring equitable access to resources, promoting the well-being of farming communities, and preserving traditional knowledge and cultural practices (Sulaiman *et al*., 2021).

Over the past few years, Mexico has created numerous sustainable agricultural development initiatives for food security (Magrini and Giambona, 2022; Badiyal *et al*., 2024); however, the demand for this staple food has risen dramatically in developing countries, leading to the intensification of maize production (Abubakar and Attanda, 2013; Badiyal *et al*., 2024). This intensification has resulted in increased use of chemical inputs, water, and land conversion, leading to significant environmental impacts (Lampridi *et al*., 2019).

Researchers have explored various strategies to enhance the sustainability of maize production, including the adoption of conservation agriculture practices, such as no-tillage, crop rotation, and cover cropping (Beltrán-Morales *et al*., 2019). These practices have been shown to improve soil health, reduce erosion, and enhance water-use efficiency (Lampridi *et al*., 2019; Badiyal *et al*., 2024). Emerging research has explored the potential of adopting agroecological practices, including intercropping and the use of organic inputs, to improve the sustainability of maize production systems in these regions (Beltrán-Morales *et al*., 2019; Magrini and Giambona, 2022; Badiyal *et al*., 2024). The practices have been shown to enhance soil fertility, reduce reliance on synthetic inputs, and support biodiversity (LaCanne and Jenks, 2018; Badiyal *et al*., 2024).

Sustainability analysis of the agricultural sector requires a comprehensive and integrated approach that considers the complex interactions between environmental, economic, and social factors. Innovative technologies and practices, such as precision farming, agroforestry, and integrated pest management, can play a crucial role in enhancing the sustainability of agricultural systems. (Cozim-Melges *et al*., 2024). Therefore, the aim of the study was to analyze the sustainability of the agricultural practices used by producers in the cultivation of maize in the ejido of San Bartolo, municipality of Acayucan, Veracruz.

MATERIALS AND METHODS

Study Area

The study was carried out in San Bartolo ejido, municipality of Acayucan, in the state of Veracruz located at coordinates 19.90889 N. and -96.9625 W (INEGI, 2009) at an altitude of 100 masl with an annual mean temperature of 24-28 ºC and with a precipitation of 1400 - 1600 mm, characterized by a warm subhumid climate with rains in summer, hills and Vertisol soils (Figure 1).

Mixed-type research was carried out, where 10 farmers were interviewed, representing 97% of the ejidatarios, considered key informants within the study. The analysis of sustainable management was based on the study carried out by Hernández-Herrera *et al.* (2018), who based it on three transversals: productive, economic, and social, using an interview. The questionnaire consisted of eight indicators: socio-cultural, economic, pre-sowing, pest control, disease control, fertilization, technological, and trade, to learn about the agronomic practices used by producers. The economic axis indicates that a maize plot is considered sustainable if it provides the economic means necessary to survive, both in terms of economic profitability and the provision of food. The productive axis allows us to identify when it improves, maintains and exerts the minimum possible negative impact on environmental resources (soil, water) and the environment (water, soil, air, flora, fauna), maintaining or increasing the yields of the corn crop; and the social axis indicates that a maize plot is considered sustainable if it maintains or improves the social capital responsible for the management of natural resources and can expand its opportunities for living.

The measurement of indicators was done according to Table 1. The data obtained were calculated with the average of each indicator, the values were made up of 1 to 0, where 1 is the optimal value and 0 is zero sustainability (Table 1).

The data are expressed in US dollars ($) with the average exchange rate of August 2024 ($19,30 Mexican pesos) reported by the Bank of Mexico (BANXICO, 2024). Financial calculation: In both farms, the economic variables were analyzed according to the following formulas:

$$Total\ costs\ = Total\ fixed\ costs\ + Total\ variable\ costs$$

$$Cost - benefit\ ratio = \frac{Income}{Expenses}$$

$$Break - even\ point\ = \frac{Total\ fixed\ costs}{Product\ selling\ price - Variable\ product\ cost}$$

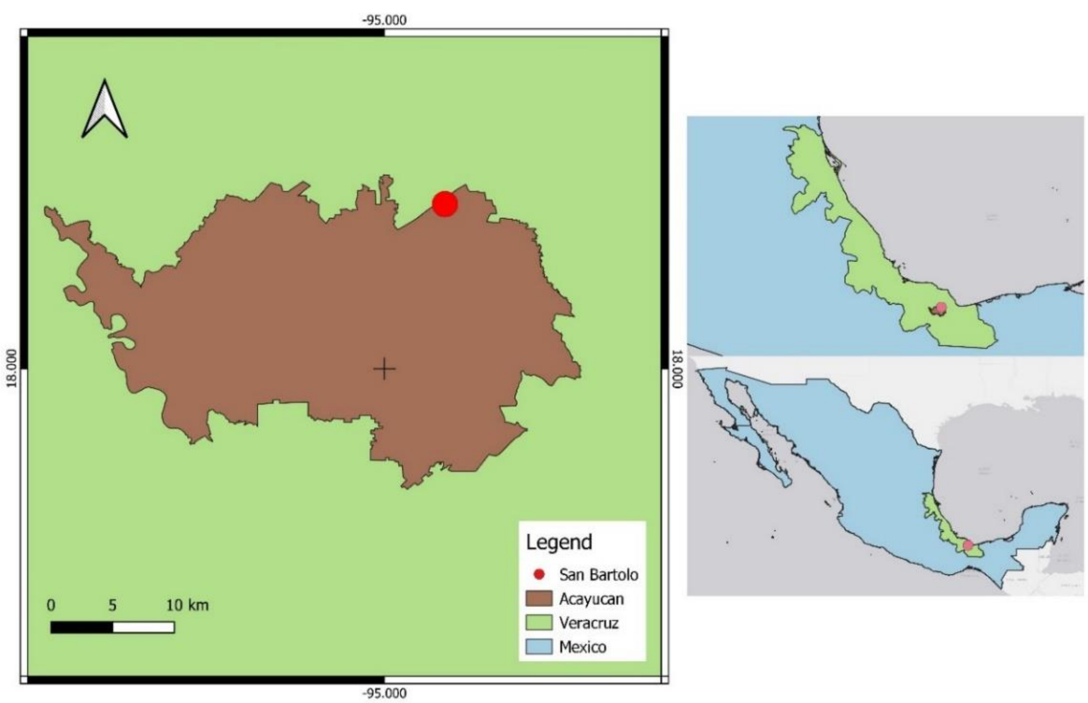

Figure 1. Location of the study zone. San Bartolo ejido, municipality of Acayucan, Veracruz, Mexico.

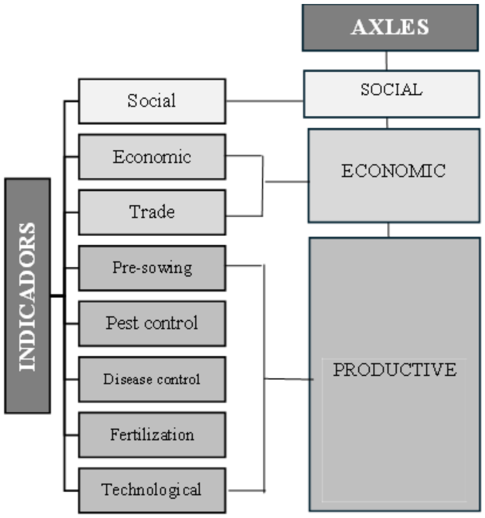

Figure 2. Cross-cutting axes and indicators of this research.

Table 1. Variables that make up the indicators for sustainable development.

Axis	Indicator	Variable	Measuring the indicator for sustainable development
Social	Sociocultural	Farmer's education	Less than 6 years (0) 6-9 years (0.33) 9-12 years (0.66) +12 years (1)
		Number of dependents	1-2 (1) 3-5 (0.5) +6 (0)
Economic	Socio-economic	Participation in any government program	Yes (0) No (1)
		Financial support	Yes (0) No (1)
		Support in kind	Yes (0) No (1)
		Agricultural Insurance	Yes (0) No (1)
	Trade	Type of clients	Local or direct sales (1) Contract companies (0.5) Intermediary or others (0)
Pest control	Pest control	Type of system	Intensive (1) Semi-intensive (0.66) Traditional-monoculture (0.33)
		Productive diversity – grow maize associated with other crops	Yes (0) No (1)
		Type of seed used	Creole (1), Variety (0.66), Hybrid (0.33)
	Pest control	Pests in the crop	Yes (0) No (1)
		Control method	Organic (1) Mixed (0.66) Synthetic (0.33) No control (0)
		Control frequency	+8 times=0 7-8 times=0.25

Axis	Indicator	Variable	Measuring the indicator for sustainable development
			5-6 times=0.50 3-4 times=0.75 1-2 times=1
	Disease control	Diseases in the crop	Yes (0) No (1)
		Control method	Organic (1) Mixed (0.66) Synthetic (0.33) No control (0)
		Control frequency	15-40 days=0 41-50 days=0.25 51-60 days=0.50 61-70 days=0.75 +71 days=1
	Fertilization	Fertilizer work	Yes (1) No (0)
		Type of fertilizer	Organic (1) Mixed (0.66) Synthetic (0.33) No control (0)
		Organic fertilizers used	None (0) Add 0.2 for each: Cow manure Sheep manure Chicken manure Compost Vermicompost
	Technological	Technical assistance	Yes (1) No (0)
		Technical assistance tracking	Yes (1) No (0)

Statistical analysis

Finally, to understand the relationship between the variables, the results were analyzed with DYANE® software version 4 (Santesmases, 2009), using the Spearman R correlation test (a ≤ 0.05).

RESULTS

The maize production system in this area is temporary, obtaining an average of 4.5 t/ha^{-1}, the most used seed is the Dekalb 390 hybrid. According to the results obtained, the social indicator showed that most farmers have less than six years of schooling, as reflected in the results with a value of 0.35, while the economic indicator revealed that half of the producers participate in the government program "Sembrando Vida", receiving economic support, but none of them have had agricultural insurance. The marketing indicator was mainly characterized by sales through intermediaries at a low price ($4.50), reflected in the data obtained from the indicator where the value is zero (Figure 3). The pre-sowing indicator showed that the majority has a traditional monoculture system characterized using hybrid seeds and no crop association. In pest control, farmers use the synthetic control method, while for disease control they do not use any method (Table 1). The fertilization indicator was characterized using synthetic fertilization, without soil analysis. Finally, the technological indicator reflected that none of the producers interviewed have external technical advice, except for the "Sembrando vida" program.

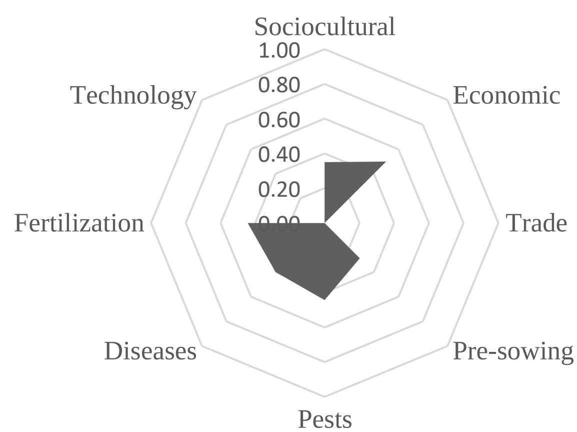

Figure 3. Indicators of sustainable development in maize crop production systems, in San Bartolo, Acayucan, Veracruz.

Production costs were provided by farmers in the area. Estimates showed that the benefit-cost ratio (B/C) was 1.05, which shows that the production system is profitable (Table 2). However, profitability is very low. Therefore, the axis with the greatest areas of opportunity is the economic one (Figure 4), since, in order to achieve high profitability values, more technical advice is needed in the agronomic management of corn crops, as well as having more efficient marketing channels.

Table 2. Production costs of agronomic management of maize crops.

Agricultural practices	Costs
Pre-sowing $ (1)	$87.56
Sowing $ (2)	$129.53
Plague $ (3)	$129.53
Diseases $ (4)	$0.00
Fertilization $ (5)	$702.07
Doubling $ (6)	$82.90
Shelling $ (7)	$93.26
Total cost ($/t) (8=1+2+3+4+5+6+7)	$1,224.87
Yield (t/ha-1) (9)	4.5
Price ($/t) (10)	$286.53
Income per ha ($) (11=9*10)	$1,289.38
Profit per ha ($) (12=11-8)	$64.51
Cost ($/t) (13= 8/9)	$272.19
Profit per t ($/t) (14=10-13)	$14.34
Benefit/Cost Ratio (15=10/13)	1.05

Note: Data expressed in US dollars. Wages and inputs are included in each corresponding agricultural practice.

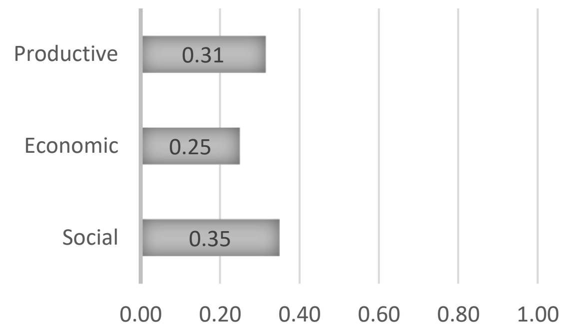

Figure 4. Cross-cutting axes of sustainable development in maize crop production systems in San Bartolo, Acayucan, Veracruz.

Finally, schooling was correlated with the amount of support they receive (R^2=0.7939, p=0.0172), since they receive more financial support in the form of school scholarships (Table 3), in addition to other social programs, this is also reflected in the higher number of economic dependents (R^2=0.8182, p=0.0000), which in turn these economic dependents have also been subject to public assistance support such as the "Pensión para el bienestar" and "Sembrando vida" programs, the latter being the main mode of technical assistance, it was the only orientation towards organic farming that producers carry out (R^2=1, p=0.0000), and finally, sales were related to a lesser extent with performance (R^2=0.6485, p=0.0517). The above may contribute to a decrease in the competitiveness of production systems, because, by receiving a greater amount of income from social support, coupled with a tendency towards low-yield production with an agroecological approach, the yield per unit of surface area decreases, and with it the efficiency of the use of resources, contrary to the principles of sustainability.

Table 3. Spearman's R correlation for the variables: Schooling, economic dependents, social programs, organic practices, technical assistance, corn production and sales.

Variables	Schooling	Dependents	Social programs	Organic practices	Technical assistance	Production	Sales
Schooling	1.0000	0.5879	0.7939	0.3394	0.3394	0.4970	0.5818
p =	0.0000	0.0778	0.0172	0.3086	0.3086	0.1360	0.0809
Dependents	0.5879	1.0000	0.8182	0.9455	0.9455	0.1091	0.0606
p =	0.0778	0.0000	0.0141	0.0046	0.0046	0.7435	0.8557
Social programs	0.7939	0.8182	1.0000	0.6182	0.6182	0.3515	0.1697
p =	0.0172	0.0141	0.0000	0.0637	0.0637	0.2916	0.6107
Organic practices	0.3394	0.9455	0.6182	1.0000	1.0000	-0.2121	-
p =	0.3086	0.0046	0.0637	0.0000	0.0000	0.5245	0.2485
							0.4560
Technical	0.3394	0.9455	0.6182	1.0000	1.0000	-0.2121	-
assistance	0.3086	0.0046	0.0637	0.0000	0.0000	0.5245	0.2485
p =							0.4560
Production	0.4970	0.1091	0.3515	-0.2121	-0.2121	1.0000	0.6485
p =	0.1360	0.7435	0.2916	0.5245	0.5245	0.0000	0.0517
Sales	0.5818	0.0606	0.1697	-0.2485	-0.2485	0.6485	1.0000
p =	0.0809	0.8557	0.6107	0.4560	0.4560	0.0517	0.0000

DISCUSSION

Sustainability in agriculture is a fundamental issue to ensure long-term food production without negatively affecting the environment (FAO, 2023). The objective is to maintain agricultural productivity through the efficient use of resources and provide better economic returns to individuals, contributing to food security (Fonteyne et al., 2019). Sustainable agriculture must meet certain objectives that include producing the necessary amount of food, being profitable for the producer, conserving non-renewable resources and harmonizing with the biological, physical and social environment (Rozenstein et al., 2023).

The results obtained show that the productive and economic transversal axes were very low (0.25 and 0.31, respectively), with a lower profitability (1.05) than reported by Mancilla *et al*. (2020) with a benefit-cost ratio of 3.83 in conventional maize cultivation but is above that reported by Ayala-Garay and Hernández-Vásquez (2023) with 0.88. This may be due to various factors, for example, farmers use synthetic fertilization without any type of advice or soil analysis, raising production costs. According to Wu *et al*. (2022), the main benefit of synthetic fertilizers is a high nutritional value, but it is ephemeral, since the excessive and constant use of synthetic fertilizers damages soil quality by deteriorating its physical and chemical properties and soil microbiota. According to Mondal *et al*. (2017), the use of large amounts of synthetic fertilization of crops should be reduced and supplemented with organic fertilizers. Likewise, Ayvar-Serna *et al*. (2020) recommend applying mineral fertilizers (NPK) in an integrated manner combined with organic fertilizers to reduce production costs. According to Rebollar *et al*. (2014), the costs of wages, fertilization, and seeds are the greatest expenses faced by maize producers. Likewise, studies show that adequate fertilization can contribute 52% more than the average net income (Medina *et al*., 2018), even with sustainable techniques such as rational fertilization (mixture of synthetic fertilizers and composts), yields can be obtained in the study area of up to 9.3 tn/Ha^{-1} (Jiménez, 2024). Recent studies have examined the potential of natural fertilizers, such as those derived from organic matter, to serve as effective substitutes for synthetic fertilizers in agricultural applications (Anwar *et al*., 2024). For example, one study analyzed the inorganic nitrogen, phosphorus, and potassium content of several natural fertilizers, including compost and animal manure, to assess their suitability for agricultural use (Morales *et al*., 2019). The findings indicate that these organic fertilizers can provide a rich source of essential nutrients for crop growth, potentially reducing the need for synthetic inputs (Kim *et al*., 2022).

An area of opportunity detected is that producers do not have technical-productive assistance to guide them on the doses of agrochemicals they need to use to control pests and diseases, as well as the rational fertilization dose for crops. Although the "Sembrando Vida" program provides agroecological support, it does not include the above, so the program has not been totally effective in increasing yields, as indicated by Montes-Ramírez and Sánchez-Juárez (2024) who found that the "Sembrando Vida" technicians from San Miguel Talea de Castro, Oaxaca confirmed the assessment made by the "sembradores", since there is a decrease in corn production due to the use of agroecological techniques, and according to the farmers themselves, the plots not incorporated into the program are more productive. In this regard, Ayala *et al*. (2013) mention that correct and timely technical advice can help reduce production costs per ton, since the use of technological packages can help increase yield per hectare (Ayala-Garay and Hernández-Vásquez, 2023). Another study investigated the potential of maize hybrids in India, highlighting the importance of understanding yield constraints to improve sustainable production and suggesting opportunities to improve productivity through better management practices (Nargal and Patil, 2020).

Ensuring the sustainability of the agricultural sector is a complex and multifaceted challenge, to promote the long-term viability of agricultural systems, and a range of innovative and environmentally friendly practices (Deprá *et al*., 2022; Rozenstein, 2023). According to the analysis, the indicators, as well as the transversal axes, showed a low level of sustainability, therefore, it is necessary to generate sustainable productive strategies in the area with technical support to increase yields. The absence of comprehensive technical advice, as well as the lack of knowledge of technological packages for the agronomic management of maize crops, brings with it the incorrect use of agrochemicals and the application dose of these (Mitra *et al*., 2021), increasing production costs, affecting yield, profitability of the crop and the environment. However, there is a problem in the application of inputs during agricultural practices, which are carried out empirically, this includes the inappropriate use of agrochemicals, which can harm human health by not using some type of protection during their application (León-Verástegui, 2012).

The data reflected that there was a significant relationship between economically dependent people and the amount of support they receive from social programs, that is, most of the family's income comes from social assistance programs. This can contribute to a decrease in the competitiveness of production systems since producers do not see agricultural activities as a real source of income. Therefore, the welfare policy allows poor families to remain at the poverty line, but not above (Velázquez, 2019). On the other hand, it has been found that older adults who receive income use part of it to accommodate their grandchildren (Aguila *et al*., 2020).

For all the above, other areas of opportunity were detected in the corn production system, such as: expanding marketing channels (Hellin *et al*., 2010), using appropriate agroecological technology that includes inputs from the region (Montes-Ramírez and Sánchez-Juárez, 2024), understanding corn agriculture as a multi-product and multi-market activity instead of a uniform production of basic products (Keleman *et al*., 2013) and developing comprehensive agronomic management practices for the crop, which include crop diversity, type of seeds used, pest control, disease control, type of fertilization and technical assistance (Shah and Wu, 2023). Finally, sustainability is a comprehensive and systemic concept, whose guiding axis in the productive field must be the balance between profitability and care for the environment (Bayram *et al*., 2024).

CONCLUSION

The sustainability analysis showed that San Bartolo producers were low in the productive (0.31), social (0.35) and economic (0.25) axes, with low yields and most of their income comes from social support.

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Compliance with ethical standards. This research meets ethical standards. Informed consent was obtained from interviewed farmers.

Data availability. Data are available upon request to the corresponding author (dlara@uv.mx).

Author contribution statement (CRediT). D. Vázquez-Luna-Conceptualization, Methodology, Visualization, Formal analysis, and Writing - original draft, review and editing, **G. Jimenez-Nestoso**-Validation, Writing, **A. Couttolenc**- Writing – original draft, Formal analysis, Visualization, **M.C. Cuevas-Díaz**- Formal Analysis, Validation, Writing - original draft, **D.A. Lara-Rodríguez**-Validation, Writing - original draft, Writing – review and editing, **G. Castillo-Capitán**- Validation, Writing - original draft.

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