





Comparison of sustainability between the dual-purpose system and the silvopastoral system in the Zoque region

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ABSTRACT

Objective: To use the IDEA method (Sustainability of Agricultural Holdings) in the analysis of the dimensions of livestock systems (LS), which allows evaluating sustainability objectively.

Methodology: The evaluation was conducted in n=24 silvopastoral systems (SPS) and n=13 dual-purpose bovine livestock systems (DPBLS) in the Zoque Valley region of Chiapas, Mexico, using the IDEA method.

Design/methodology/approach: The resulting indicators were analyzed with the IBM SPSS statistical package, determining their normality, association and difference in the values obtained.

Results: The sustainability of SPS is defined by the socio-territorial scale (54.26), while in DPBLS the influence of the economic scale predominates (48.92). Statistically, there are no significant differences in the sustainability indicators between both systems.

Limitations on study/implications: In the LS studied, although they have similar levels, sustainability is determined by different factors. This divergence indicates that, while SPS prioritize holistic sustainability through agroecological synergies, DPBLS face the challenge of balancing profitability with responsible environmental practices.

Findings/conclusions: The absence of significant differences in sustainability denotes that management practices are decisive in the management of sustainability in the LS. More studies are required to evaluate the sustainability of the LPUs, as well as implementing public policies that establish rules for the responsible use of natural resources and the transfer of technologies.

Keywords: Agroecological; socio-territorial; economic; sustainability; silvopastoralism.

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INTRODUCTION

Bovine livestock production faces several challenges and key trends; global production of bovine meat continues growing, global consumption shows diverse patterns with increases in developing countries and a tendency towards reduction in some developed regions,



and there is a growing preoccupation over the environmental impact of bovine livestock production (FIRA, 2024), especially regarding greenhouse gas emissions (FAO, 2023). Therefore, this demands increasing productivity without compromising environmental, economic and social sustainability; within this context, dual-purpose bovine livestock systems and silvopastoral systems have been promoted as effective alternatives to balance the production of meat and milk with the conservation of natural resources (Gutiérrez Bermúdez and Mendieta Araica, 2022).

Mexico is an important producer of bovine livestock, both for meat and for milk. Production is divided mainly between meat, dual-purpose, and dairy livestock; the traditional extensive system predominates, especially in tropical and arid zones, although there is a rise in intensive and semi-intensive systems, where small-scale and medium-scale producers represent a significant part of the sector (Pérez Chabela and Lamothe Zavaleta, 2019).

Livestock production in Chiapas is in a phase of growth and modernization, it is an essential economic activity that has shown notable growth in recent years; however, it faces sanitary and environmental challenges, although it has also adopted sustainable practices that seek to ensure its viability and competitiveness in the long term (Vargas-de la Mora, 2018; Orantes-Zebadúa *et al.*, 2014).

The dual-purpose bovine livestock system (DPBLS) maximizes the productive efficiency by obtaining milk and meat simultaneously from the same herd, adapting to various agroecological conditions, and favoring food security; this contributes to the wellbeing of rural communities because it can simultaneously provide security in daily sustenance, conserve ecosystems, generate stable jobs for people in rural areas, and also constitutes the economic basis of millions of livestock and industrial producers (Cuevas-Reyes and Rosales-Nieto, 2018). Dual-purpose livestock production is common in countries with tropical and subtropical climates, where conditions are favorable for grazing and fodder production; it presents great heterogeneity in terms of breeds, levels of production, infrastructure, handling, investment, technology and management, which allows it to adapt to different zones and producers (García-Martínez *et al.*, 2015).

Silvopastoral systems (SPS) integrate tree and fodder species in a productive ecosystem, improving the quality of the soil, animal welfare, and resilience in the presence of climate change, in addition to promoting soil regeneration, carbon sequestration, and biodiversity (Aguilar Pérez *et al.*, 2019; López-Vigoa *et al.*, 2017). SPS seek to improve and modernize livestock production, while they contribute to reducing environmental problems, improving animal welfare, increasing animal productivity, and generating environmental services; they also adapt to the customs and traditions of the regions where they are implemented (López-Vigoa *et al.*, 2017; Alders *et al.*, 2021).

To ensure the long-term viability of these systems, it is crucial to have tools that allow evaluation in an objective and structured manner their level of sustainability. There are various methodologies used to evaluate the sustainability of livestock production systems, through which their environmental, social and economic impact is analyzed. The most frequently used, which include specific metrics (indicators of sustainability) that allow evaluating different aspects of the livestock production system, are: Evaluation Framework

of Natural Resources Management with Sustainability Indicators (*Marco de Evaluación de Sistemas de Manejo de Recursos Naturales con Indicadores de Sustentabilidad*, MESMIS); FAO indicators for the Sustainability Assessment of Food and Agriculture systems (SAFA); Response-Inducing Sustainability Evaluation (RISE); and Sustainability Indicators of Agricultural Holdings (*Indicadores de Sustentabilidad de las Explotaciones Agrícolas*, IDEA) (Berbec *et al.*, 2018).

The IDEA method has been consolidated as an integral model for the evaluation of sustainability thanks to its adaptability to different agriculture and livestock production systems, since it allows analyzing three fundamental dimensions: environmental, economic and social, through gathering and easy measurement of information from the livestock production units (LPUs), providing quantifiable indicators that facilitate decision making and the design of improvement strategies (Prospero Bernal, 2017; Torres-Lemus *et al.*, 2021). Therefore, the objective of this study was to analyze the sustainability of dual-purpose livestock systems compared to silvopastoral systems, using the IDEA method.

MATERIALS AND METHODS

The study was conducted in the Zoque Valley region in Chiapas, Mexico. With a total surface area of 7,393.76 square kilometers, it borders to the north with Region III Mezcalapa and the state of Veracruz, east with Region I Metropolitana, south with Regions VI Frailesca and IX Istmo Costa, and west with the state of Oaxaca; the altitude of the territory ranges from 60 to 2,054 meters above sea level; humid and subhumid warm climate with rainfall regime marked with summer precipitations predominates, and mean annual temperature in the range of 24 °C to 26 °C (CEIEG, 2012).

The information was obtained through intentional or snowball sampling, based on Martín-Crepeo Blanco and Salamanca Castro (2007); surveys and semi-structured interviews were conducted with cooperating producers and workers from 37 livestock production units (LPUs), of which 23 are SPS and 14 are DPBLS located in the municipalities of Cintalapa, Jiquipilas and Ocozocoautla.

The data obtained were organized and analyzed in Microsoft Excel 2019. Then, information analysis was carried out to evaluate the sustainability of the production systems, through the IDEA (Indicators of Sustainability in Agricultural Holdings) methodology, version 3, which was developed in France (Vilain *et al.*, 2008; Zahm *et al.*, 2008; Hamadi *et al.*, 2009).

The resulting indicators of sustainability from the IDEA method for SPS and DPBLS were analyzed using the IBM SPSS statistical package, performing the Shapiro-Wilk normality test to determine if the variables follow a normal distribution. The correlation coefficient between indicators of the systems was also determined, through Spearman's test, to measure the strength and the direction of the association between variables. In addition, the Mann-Whitney U test was carried out to compare the indicators from both systems and to determine if there are significant differences between the samples in terms of their central tendency (Field, 2013).

RESULTS AND DISCUSSION

Silvopastoral systems (SPS) and dual-purpose bovine livestock systems (DPBLS) present structural differences in their priorities of sustainability, as the results from the IDEA methodology show. The sustainability of SPS is determined primarily by the socio-territorial scale (54.26), which evidences a series of limitations: lack of infrastructure for livestock production development; low coverage of social security programs; need to improve productive efficiency; scarce generation of employment; low educational level of producers; and uncertainty regarding the permanence of new generations in the LPUs. All these factors hardly have an average impact on the standard of living. In DPBLS, sustainability is influenced mainly by the economic scale (48.93), which denotes the need to destine resources to animal feeding, as well as to sowing and harvesting of the crops, in addition to a lack of income from alternative activities (Figure 1).

The comparative analysis of the variances did not evidence statistical differences between the values of the indicators corresponding to SPS and DPBLS systems. Consequently, based on the data analyzed, both systems present similar behaviors in the aspects evaluated (Figure 2).

The statistical analysis of the indicators of the agroecological scale (A1-A18) reveals different perceptions. In SPS, strengths with higher diversity of perennial crops (A2: 7.4 *vs.* 6.4) and greater presence of ecological regulation zones (A8: 7.4 *vs.* 5.8) stand out, as well as better management of fertilization (A12: 6.9 *vs.* 2.9), protection of soil (A16: 5.0 *vs.* 3.9), and high energetic autonomy (A18: 8.7 *vs.* 2.7). However, both systems present a shared limitation: the null use of genetic patrimony (A4: 0). For their part, DPBLS present advantages with higher animal diversity (A3: 12.1 *vs.* 8.3), better management of the fodder surface (A11: 2.5 *vs.* 2.3), and lower animal load (A10: 3.3 *vs.* 3.8), which contributes to reducing the ecological pressure.

In the socio-territorial scale (B1-B18), SPS stand out for having greater autonomy in the use of local resources (B7: 7.7 *vs.* 6.7), collective work (B10: 1.5 *vs.* 0.4), and social participation (B5: 3.0 *vs.* 2.3), aspects aligned with the criteria of equity. On the other hand, DPBLS stand out for having greater generation of employment (B9: 4.8 *vs.* 3.0),

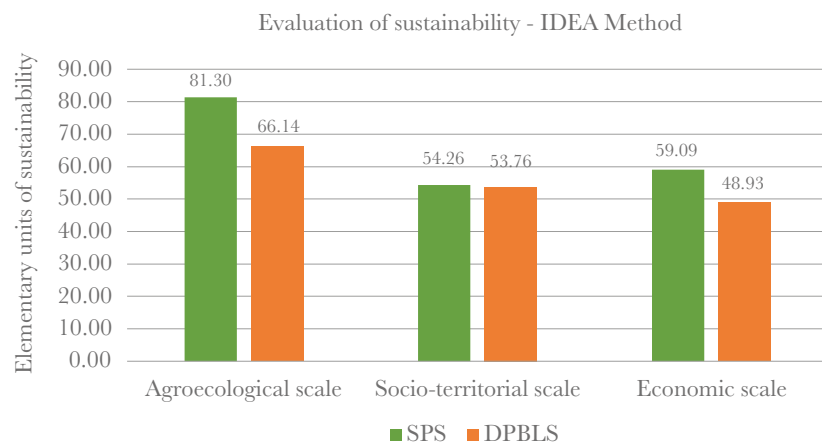


Figure 1. Determination of the sustainability scales using the IDEA Method.

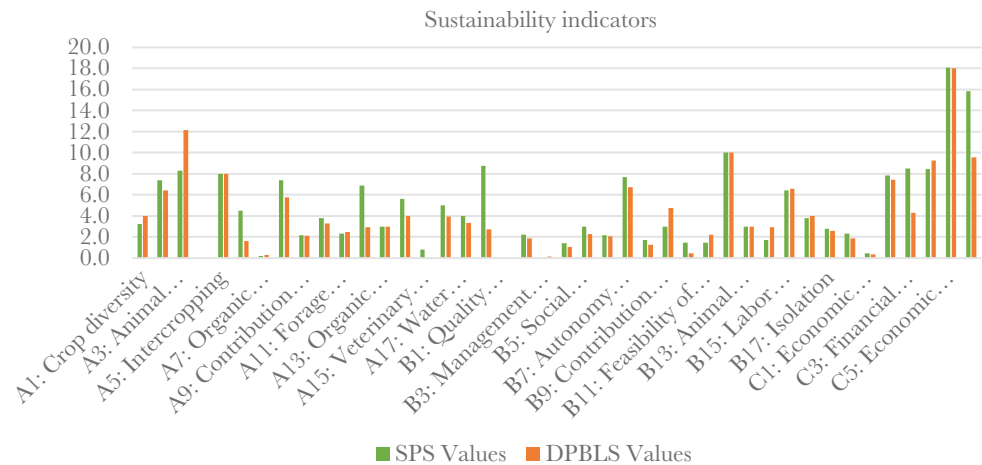


Figure 2. Homogeneity test by comparing variances of SPS and DPBLS.

higher educational level of producers, reflected in the indicator of training (B14: 2.9 *vs.* 1.7), and higher labor intensity (B15: 6.6 *vs.* 6.4), which evidences more active productive dynamics. However, both systems share weaknesses in quality processes (B1: 0) and in the management of non-organic residues (B3: ≤ 0.1).

The indicators that make up the economic scale (C1-C6), show that SPS present greater advantages thanks to their high financial autonomy (C3: 8.5 *vs.* 4.3), higher productive efficiency (C6: 15.8 *vs.* 9.6), and lower dependency on subsidies (C4: 8.4 *vs.* 9.3). For their part, DPBLS show a more marked economic specialization (C2: 7.4 *vs.* 7.8). When it comes to economic transmissibility, the indicators are practically equivalent (C5: 18.0 *vs.* 18.1), and so is the economic viability (C1: 0.4 in both cases), which suggests shared challenges in terms of profitability.

The analysis of relationships and interactions between components of sustainability in both productive systems is presented in Figure 3, which shows that the social, economic and environmental factors are interconnected and contribute in a differentiated manner to the sustainability of each system.

The comparison of components of sustainability indicates a strong relationship and interaction between both systems. However, there are slight trends: SPS have strengths in organizational and ecological aspects, and in the organization of spaces they present better distribution of the territory, making them more efficient and adaptable. In agricultural practices, SPS have higher scoring, revealing the use of more sustainable techniques, which is reflected in a greater efficiency of the system. Meanwhile, DPBLS stand out slightly in the component of diversity, which suggests a greater variety in crops, species and/or activities, as well as in socioeconomic aspects such as employment. Both face important challenges in efficiency, viability and transmissibility of the productive system towards the future, which must be addressed in policies for sustainable rural development.

The Shapiro-Wilk normality test (Table 1) shows that the values of the indicators in both systems do not follow a normal distribution ($p < 0.05$), which justifies the use of non-parametric statistical tests to evaluate differences between them.

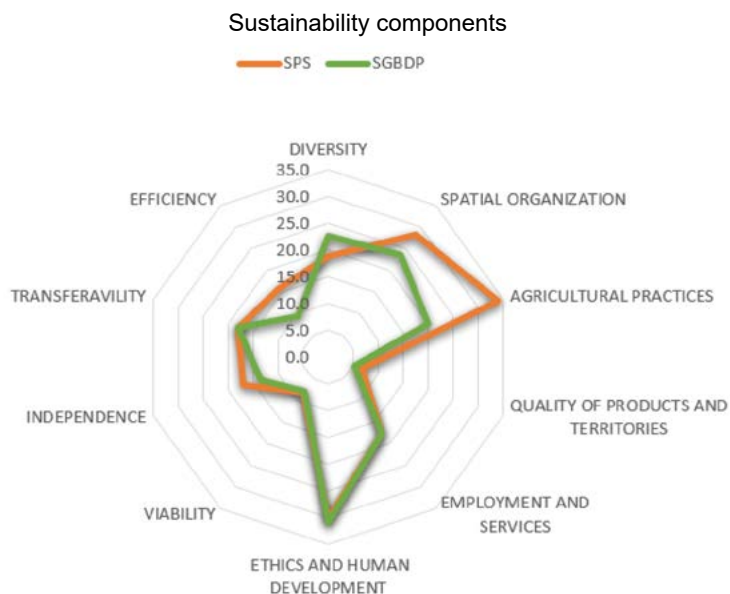


Figure 3. Relationships and interactions of the components that determine the sustainability of SPS and DPBLS.

Spearman’s correlation coefficient (Table 1) indicates a very strong positive relationship between the values of sustainability of SPS and DPBLS ($\rho=0.895$, $p<0.001$). This result confirms that both systems present similar trends in terms of their indicators of sustainability, which suggests that they share key factors that determine their performance.

On the other hand, the Mann-Whitney U test (Table 3) did not show statistically significant differences between the values of the indicators of sustainability of SPS and DPBLS ($p=0.485$). This implies that, although there are differences in the dominating scale of sustainability in each system, their global levels of sustainability are comparable.

Finally, the dispersion graph (Figure 4) shows the strong correlation observed between the sustainability values of both systems, represented by a line of positive tendency, which reinforces the consistency of the statistical findings.

Table 1. Shapiro-Wilk normality test.

	Statistics	Degrees of freedom	P-value
SPS Values	0.86	42	0.00
DPBLS Values	0.84	42	0.00

Table 2. Spearman correlation of SPS and DPBLS sustainability.

	ρ	p	N
SPS-DPBLS	.895**	.000	42

Table 3. Mann-Whitney U test.

	Statistics	p
System value	804	0.485

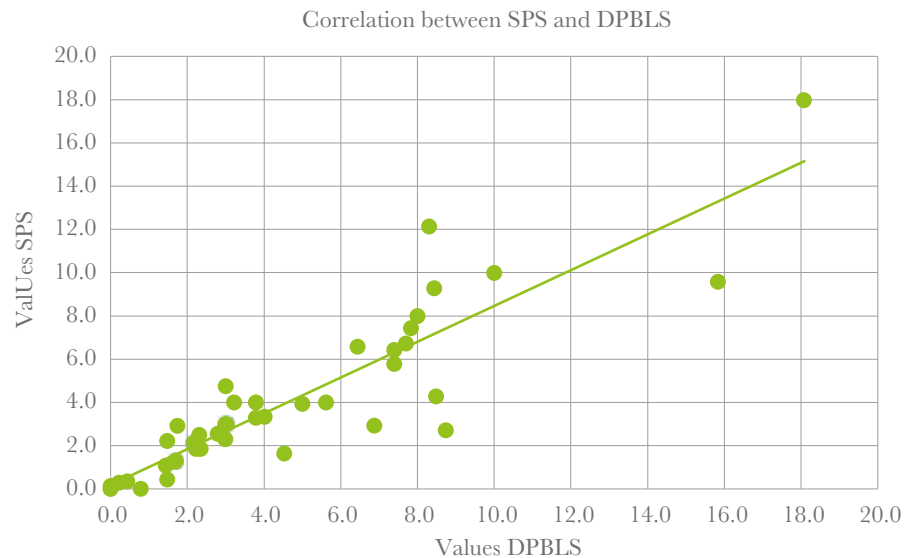


Figure 4. Results of the Correlation Significance Tests.

The results obtained indicate that SPS and DPBLS present a similar behavior in the aspects evaluated. However, the global valuation of these indicators indicates that both systems are still under the thresholds that characterize sustainable management (Otta *et al.*, 2016). This divergence is explained by the operative characteristics and the approaches of each productive system, which agrees with the observations from many authors (Reyes Pontet *et al.*, 2023; Gutiérrez Bermúdez and Medieta Araica, 2022; Haro-Altamirano *et al.*, 2022).

Based on the approach of the IDEA methodology, if the socio-territorial scale is defining for SPS, it reveals the need to strengthen processes such as the improvement in product quality, the conservation of territories, the generation of dignified employment, and the provision of community services. Likewise, human development and ethics emerge as fundamental pillars that must be prioritized in any strategy directed towards sustainability. In line with this perspective, Murgueitio *et al.* (2019) emphasize that sustainable systems should not only be productive, but also capable of generating ecosystemic services that contribute to social and environmental welfare. From this same conceptualization, Rozo *et al.* (2021) and Williams *et al.* (2020) emphasize that these systems contribute to the creation of biological corridors and to strengthening community resilience, essential aspects within the socio-territorial dimension. Chará *et al.* (2017) add that the integration of trees allows producers to diversify their income through the use of wood and non-wood products. These dynamics agree with the findings by Aguilar Pérez *et al.* (2019) and López-Vigoa *et al.* (2017), who highlight the importance of incorporating these systems in rural communities, both because of their contribution to conservation of ecosystems and for their role in sustainable territorial development.

In contrast with SPS, whose sustainability is closely linked to the socio-territorial dimension, in DPBLS the influence of the economic dimension predominates. In DPBLS, sustainability is determined to a greater extent by the economic scale, which evidences a

strong dependency on factors such as profitability and productive efficiency to ensure its viability (Cuevas-Reyes and Rosales-Nieto, 2018; Angón *et al.*, 2016).

While SPS prioritize holistic sustainability through agroecological synergies, DPBLS face the challenge of balancing profitability with environmentally responsible practices. Gallardo *et al.* (2019) and Murgueitio *et al.* (2015) agree that the integration of arboreal components could improve integral sustainability in livestock production systems, in addition contributing to environmental care by reducing the methane emissions by product unit by 20-30%.

SPS showed greater diversity of perennial crops and higher proportion of ecological regulation zones, compared to DPBLS, which reflects significant advantages in terms of biodiversity and environmental conservation. These results agree with what is suggested by Gutiérrez Cedillo *et al.* (2011), who emphasize the need for more effective integration between the agricultural, livestock and forestry subsystems as a pathway to strengthen the sustainability of productive systems.

The high correlation coefficient between both systems suggests the existence of common structural factors that impact their performance in terms of sustainability. This result backs the hypothesis that SPS and DPBLS can share intervention strategies directed at improving management of natural resources, optimizing access to markets, and fostering adoption of sustainable technologies (Zahm *et al.*, 2008). However, the absence of statistically significant differences between both models indicates that neither presents a clear comparative advantage in terms of integral sustainability, which can be related to the variability in management conditions, as well as differences in access to public policies and technical-productive support programs (Prospero Bernal, 2017; Torres-Lemus *et al.*, 2021).

The results obtained highlight the need to design integrated strategies directed at strengthening the different dimensions of sustainability in both productive systems. These strategies must focus on the optimization of the use of natural resources and the adoption of practices that reduce environmental impact without compromising economic profitability (Vilain *et al.*, 2008).

Likewise, it is recommended that future studies approach the evaluation of sustainability in the long term, incorporating emerging variables such as climate change and availability of water resources, since these factors could significantly influence the sustainable performance of the systems analyzed (Hamadi *et al.*, 2009), which will allow identifying territorial patterns of sustainability, as well as designing strategies of differentiated improvement based on specific technical, socioeconomic and ecological indicators. The implementation of systemic and participatory approaches in the formulation of appropriate technologies and support policies could be key to boost the existing synergies and to advance towards a more sustainable and resilient management of both productive systems.

CONCLUSIONS

The findings obtained reveal a high correlation between the SPS and DPBLS systems, which indicates the presence of common structural factors that impact their sustainability. This convergence suggests that both models can benefit from shared

strategies, focused on the efficient management of the resources, access to differentiated markets, and the adoption of sustainable technologies. However, the lack of statistically significant differences between the systems in terms of global sustainability reflects that neither presents a substantial comparative advantage, possibly due to the heterogeneity in the conditions of management, local practices, and availability of policies for productive support.

The high degree of correlation between the systems highlights the importance of implementing integrated strategies that allow improving productive efficiency without compromising environmental and social sustainability. The absence of significant differences in the levels of sustainability between both systems reinforces the idea that management practices can play a crucial role in their sustainable performance.

In this context, the need to study multi-scale and multi-dimensional approaches in more detail, which would allow to identify differentiated territorial dynamics and to direct more contextualized intervention strategies, stands out. The development of specific technical policies, sustained by socioeconomic, ecological and local governance indicators will be essential to promote a sustainable transition in both productive models and to contribute to strengthening their resilience in face of current environmental and economic challenges.

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