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Multifunctionality in maize production systems in the Mixteca Alta region of Oaxaca

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ABSTRACT
Objective: To infer the role of multifunctionality in the milpa systems of the Mixteca Alta region of Oaxaca, Mexico.
Design/Methodology/Approach: The methodological framework of the Multifunctionality Index of Agricultural Production Systems (IMSPA) was used, applying semi-structured interviews to producers.
Results: The multifunctionality level of each evaluated systems was determined and the Milpa Intercropped with Fruit Trees (MIAF) showed the greatest multifunctionality and potential attributes for local development.
Study Limitations/Implications: The resistance among producers to make changes in their plots usually leads to a refusal to participate and to mistrust this type of research.
Findings/Conclusions: It is necessary to follow up on multifunctionality evaluations, since some systems are at a point where their functions can advance or regress.

Keywords: Intercropped milpa, MIAF system, multifunctional agriculture.

INTRODUCTION

In recent years, alternative approaches that allow better use of the land have emerged. The multifunctionality of agriculture (aka, multifunctional agriculture) is one those approaches and refers to the ability to generate different types of products and services derived from agricultural practices (Gómez-Limón *et al.*, 2008; Silva, 2010). These practices have a direct impact on the economy and society as a whole (Bonnal *et al.*, 2003). In addition, multifunctional agriculture directly contributes to well-being and social inclusion, through the increase in the flow of money, ecotourism activities, and the management and appreciation of natural resources (Ikova and Todorova, 2014). From its origin, the concept of multifunctional agriculture (MFA) has drawn the attention of academics, institutions, and countries (Cuevas *et al.*, 2015).

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MFA has been practiced by small farmers in rural communities as a self-sufficiency and diversification strategy for decades; however, it was not considered in global development, political, and science forums before the Rio Earth Summit of 1992 (Callo-Concha, 2018). In 2001, the Organization for Economic Co-operation and Development (OECD) established the objectives of the MFA, highlighting the preservation of production and consumption, the promotion of agricultural development, and the improvement of the economic benefit of farmers (OECD, 2001).

In Mexico, one of the main multifunctional agricultural systems is the milpa, particularly in rural regions where the main crop is maize, which can be associated with both domesticated and wild species (Cotler-Ávalos and Lazos-Chavero, 2019). This production system has a spatiotemporal dynamic, related to the natural environment (soil, microclimates, nutrients, water), the socio–cultural context (family dynamics, lore, practices, institutional arrangements), and the economic–political aspects (market behavior, labor, development policies). This situation leads to multiple crop management and decisions, making the milpa an exponentially complex and multifunctional agroecosystem (Lazos, 1995; Cotler-Ávalos and Lazos-Chavero, 2019).

Within the Mexican territory, the southeastern region is where maize (*Zea mays* L.) cultivation is most important and it is considered one of the centers of origin of this species (Salinas Moreno *et al.*, 2013). Approximately 90% of the cultivated maize surface of the State of Oaxaca is sown with native maize of different races, colors, textures, and crop cycles (Aragón *et al.*, 2006). There are areas where maize is grown in interaction with other crops and fruit trees (MIAF); this interaction provides more benefits than monocultures (traditional milpa) (Turrent *et al.*, 2017).

The Mixteca Alta region of Oaxaca is a mountain range whose inhabitants cultivate the milpa in a traditional way; nevertheless, some of them are gradually adopting and implementing other multifunctional production systems. The multifunctionality of the milpa in this region has not been evaluated yet, neither with the systems analysis or any other approach. Therefore, the objective of this study was to determine the multifunctionality of milpa systems in the Mixteca Alta region of Oaxaca, Mexico.

MATERIALS AND METHODS

Methodological framework of the Multifunctionality Index of Agricultural Production Systems (IMSPA)

The IMSPA is an index made up of two interrelated key concepts: agroecology and sustainable development. It takes up the systemic perspective of agriculture and defines the agricultural production system itself as the level of analysis. It has a local approach, in which the producers manage the resources and, consequently, their agricultural practices have an impact on the surrounding environment. The index allows the evaluation of the multifunctionality degree to which an agricultural production system contributes through four areas: 1) Territorial Scope (TS); 2) Environmental Scope (EnS); 3) Economic Scope (EcS) and; 4) Social Scope (SS). These areas were analyzed using 12 functions (three per scope) (Figure 1).

Function 1: Landscape settings. Exclusionary variable: Spatial heterogeneity Indicator: Number of crops established in the last year. -One crop, value = 1.75 -2 to 3 crops, value = 3.5 -4 to 5 crops, value = 5.25 -Greater than 6 crops, value = 7	**Territorial scope**	**Economic scope**	**Function 7: Rural viability.** Excluding variable: Employment. Indicator: Type and duration of employment generated -Temporary family employment, value = 2.5 -Constant family employment, value = 5 -Constant and temporary external family employment, value = 7.5 -Constant family and external employment, value = 7.5
Function 3: Agricultural history. Excluding variable: Exchange holding Indicator: System orientation determined by the number of crops developed over time. -Simplification (crop reduction) value = 2.33 -Stable (equal number of crops) value= 4.66 -Complexity (crop increase) value = 7	**Function 2: Spatial connectivity.** Additive variable: Source of supply. Indicator: Type of source of water for the development of the system. -Value by type = 1.2 -Irrigation unit/district -Rain -Water dam -River -Waterhole	**Function 8: Strengthening local economy.** Excluding variable: Market. Indicator: Production integrated to the local market. -No distribution, value = 1.875 -Distribution external to the locality, value = 3.75 -Local and external distribution, value = 5.625 -Local distribution only, value = 7.5	**Function 9: Food security.** Excluding variable: Self-consumption. Indicator: Production for direct or indirect self-consumption through a livestock subsystem -Only direct consumption, value = 2.5 -Only indirect consumption, value = 5 -Direct and indirect consumption, value = 7.5
	Index of Multifunctionality of Agricultural Production System		
Function 4. Provision of shelter and habitat. Additive variable: Wildlife protection Indicator: Sighting of burrows. Value by type = 1.125 -In arboreal stratum -In stone fences or other materials -In subsoil or wall -In cultivation	**Function 5. Soil and water conservation.** Additive variable: Sustainable strategies Indicator: Implementation of enabling practices Value by practice = 1,683 -Incorporation of organic matter -Vermiculture practices -Soil rehabilitation -Cover crops -Contour furrow -Crop rotation -Minimum tillage -Drip irrigation	**Function 12: Social cohesion.** Excluding variable: Participation. Indicator: Degree of participation in social platforms- -No integration, value = 0 -If you belong to any social group, value = 2.1875 -If you attend meetings, value = 4.375 -If you participate in agreements, value = 6.5625 -Is part of the organizational group, value = 8.75	**Function 11: Territorial roots.** Excluding variable: Local price. Indicator: sense of belonging -Land lent or rented and external origin, value = 1,875 -Own land and external origin, value = 3.75 -Land rented or lent and local origin, value = 5,625 -Own land and local origin, value = 7.5
Function 6. Preservation of biodiversity. Additive variable: Promotion of diversity Indicator: Practices to promote biodiversity. Practical value = 3 -Incorporation of more than one variety per crop -Use of two or more different crops -Use of hedges in burrows and/or within the system -Incorporation of livestock activity	**Environmental scope**	**Social scope**	**Function 10: Protection of cultural heritage** Additive variable: Agricultural worldview. Indicator: Availability and/or practice of the producer. Value by option: 1.75 -Use various crops in time and space -Produce without chemical inputs or machinery -Use ecological interdependencies to prevent pests and diseases -Produce in adverse environments due to temperature and / or slope of the land -Use wild plants and/or animals medicinally

Figure 1. General composition of the IMSPA.

The sum of all the scopes integrates the value of the IMSPA.

$$IMSPA = TS + EnS + EcS + SS$$

Where:

$$\frac{TS\left(Territorial\ Scope\right) = \sum Functions\ 1,2,3}{Maximum\ EnS\ value = 20}$$

$$\frac{EnS\left(Environmental\ Scope\right) = \sum Functions\ 4,5,6}{Maximum\ EnS\ value = 30}$$

$$\frac{EcS\left(Economic\ Scope\right) = \sum Functions\ 7,8,9}{Maximum\ EnS\ value = 25}$$

$$\frac{SS\left(Social\ Scope\right) = \sum Functions\ 10,11,12}{Maximum\ SS\ value = 25}$$

The IMSPA has a 0-100 scale. When a system is closer to 100, its multifunctionality is greater. It is classified into five categories that define its multifunctionality degree. It also helps to locate the result of the system's status; consequently, an ongoing monitoring leads to an increase in the speed of the changes (Table 1).

Table 1. IMSPA categories.

IMSPA Categories	Definition
I (<20) Low multifunctionality	System in critical state due to the minimum contribution of functions both inside and outside it, located at the extreme of the conventionality of its form of production.
II (20.1 - 40) Medium-low multifunctionality	System thet in its greatest production is handled in a conventional way, can have a marked contribution in any of the four scopes.
III (40.1 - 60) Intermediate multifunctionality	System in a vulnerable state to improvement or setback in terms of the production of functions.
IV (60.1 - 80) Medium-high multifunctionality	System in a favorable path to produce functions in the various fields, although not proportionally. It is considered that these systems defined their paths towards diversification and develop practices that benefit the multifunctionality of the system.
V (80.1 - 100) High multifunctionality	Category that defines an excellent state in terms of the contribution of functions in the four scopes that the system generates and that have a positive impact on the environment and society. Ideal systems to replicate or augment.

Study area

The Mixteca is one of the eight regions that make up the State of Oaxaca. It is located in the northwest of the state and covers an area of 15,671.08 km^2. The Mixteca Alta is an area characterized by high mountains, where flat morphology is scarce and the Nochixtlán valley is the most extensive flat area (Solís-Castillo *et al.*, 2018).

The dominant climate is temperate sub-humid with rainfall in summer (Cw) and a marked midsummer heat period between July and August (García, 2004). The mean annual temperature is 15 °C and the average annual rainfall is 649 mm. The predominant vegetation is secondary pine and oak forest in the upper parts, with some primary relicts (Solís-Castillo *et al.*, 2018).

Asunción Nochixtlán is one of the seven districts that make up the Mixteca region. The municipalities of Santa María Apasco, Santiago Apoala, and San Miguel Huautla are located in this district (Figure 2). Their inhabitants cultivate maize under different Agricultural Production Systems (APS).

RESULTS AND DISCUSSION

Application of IMSPA to maize systems

Eight agricultural production systems (PS) —which together cover an area of nine hectares— were identified and evaluated in the three selected communities (Table 2). The APS and the plots were located through key informants who are aware of the local agricultural management. Each APS was considered as a level of analysis and a semi-structured interview was applied to the person responsible for its management, in order to evaluate both the APS and its producers. The surveys were applied from May to July 2022.

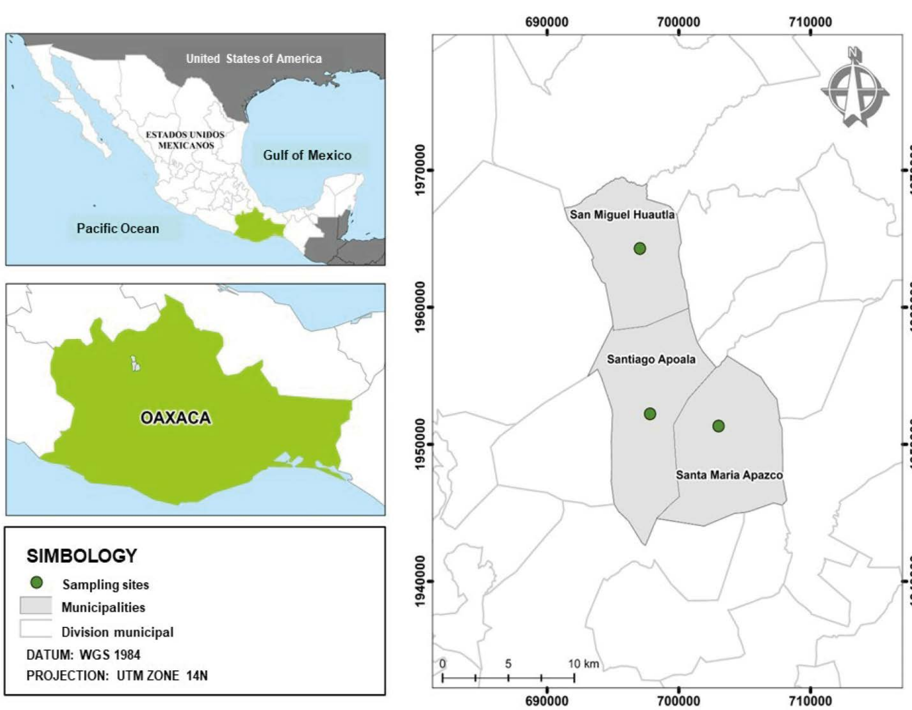

Figure 2. Location of the sampling sites in the Mixteca region of Oaxaca, Mexico.

Table 2. General characterization of the Agricultural Production Systems evaluated.

System	Area (ha)	General characteristics
Apasco corn	1.0	Conventional cultivation with application of agrochemicals, production for consumption and sale
Apoala corn	1.5	
Huautla corn	1.0	
Corn-Bean Apasco	0.5	Conventional cultivation with application of agrochemical, small areas, with production destined for corn for consumption, and beans for consumption and sale
Corn-Bean Apoala	0.5	
Corn-Fruit Apoala	1.5	Intercropping with milpa and fruit trees such as: peach, avocado, apple. They are not governed by the methodology of the MIAF system.
Corn-Fruit Huautla	1.0	
MIAF Apasco	1.0	It is characterized by following the methodologies of sowing, planting, pruning and fertilization of the MIAF system. The fruit trees are peach, apple and avocado.

Multifunctionality of agricultural production systems in the Mixteca Alta region of Oaxaca

The analysis of the 12 functions for each of the four evaluated areas (territory, environment, economy, and society) are shown below, along with their graphic representation and their integration into the IMSPA. It is important to mention that the variables and functions included do not limit the broad concept of multifunctionality; however, they certainly contribute to the way in which it can be approached.

Territorial scope

The landscape configuration function is mainly understood as the result of the management of natural resources by human beings (Ruiz *et al.*, 2016). The components of the agricultural landscape act as jigsaw pieces that can favor or interrupt environmental processes and ecosystem services (Francesconi and Montagnini, 2015; Clemente-Ortega and Álvarez, 2019). Therefore, a production system directly influences the landscape by creating a composition that indicates functionality and continuity: the greater the spatial heterogeneity, the greater the multifunctionality (Ruiz *et al.*, 2016). The indicator used to evaluate the said heterogeneity was the number of crops implemented per year. The results for this function showed that no system had more than six crops established in the last year: 12.5% of the evaluated systems implemented 4 to 5 crops, 37.5% established 2 to 3 crops, and the remaining 50% only had 1 crop.

Agriculture is an economic activity that consumes a high amount of water resources. The spatial connectivity function considers the importance of production systems in the continuity or fragmentation of the agricultural space; this function does not only impact the landscape, but also interrupts ecological interactions (Ruiz *et al.*, 2016). Water was considered as a fundamental requirement for the productivity and continuous production of agricultural systems. On the one hand, having a non-rainfall supply source will be decisive. On the other hand, the source of water was considered for the evaluation of the function. The results showed that rain is the only source of water supply in five systems, while the remaining three have an alternate source that guarantees the continuity of production.

Lastly, the agricultural history function considers that crop changes in the system allow the restructuring of the landscape of a given territory, determining its specific characteristics. Consequently, it was possible to identify the systems' tendency towards complexity (increase in the number of crops), constancy (same number of crops), or even simplification (reduction of crops). Changing from a monoculture to agroecological diversification promotes natural processes that preserve the health, productivity, and self-sustainability of the agroecosystem (Nicholls *et al.*, 2015). The results showed that 87% of the evaluated systems has a stable trend, because the producers have always developed the same number and type of crops, while only 12.5% (one system) has a trend towards complexity and increases on a regular basis (Figure 3).

Environmental scope

The refuge and habitat provision function considers that a production system can provide refuge for wildlife, forming microhabitats in which different species can develop (Canavellis and Zaccagnini, 2007; Figueroa-Sandoval *et al.*, 2019). Therefore, the sighting of burrows and nests within the system is a good indicator of multifunctionality (Ruiz *et al.*, 2016). Burrows and nests were only observed in one location within each system (fences, subsoil, and inside the crop). No sightings were recorded in the MIAF - Apoala, while in the MIAF - Apasco they were found in two different locations within the system (fences made of stone or other materials and in the subsoil). More burrows were recorded within this crop than in others.

The soil and water conservation function considers that agricultural practices have a direct impact in the conservation or deterioration of these resources. Adopting and implementing new soil conservation techniques will pose a major challenge for authorities, producers, and academia (Gómez-Calderón *et al.*, 2018). Minimum tillage is the most frequently used of the eight practices evaluated in this research. In addition, in the Maíz - Huautla system only one practice is carried out, in contrast with the MIAF - Apasco

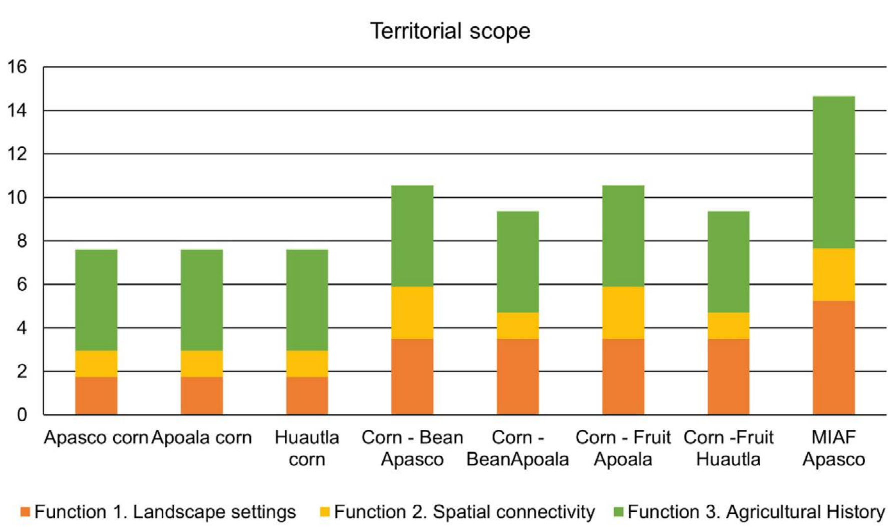

Figure 3. Accumulated value of functions for the territorial scope by system.

system, which recorded the highest number of implemented techniques (incorporation of organic matter, soil rehabilitation, crop rotation, minimum tillage, and drip irrigation).

The biodiversity preservation function considers the management that the producer carries out to promote the conservation of biodiversity in the system. The FAO (1999) mentions that the different agricultural practices can have a positive or negative impact on diversity and, that the greater the promotion of diversity, the greater the multifunctionality displayed by the system. Aiming agricultural practices towards a diverse agroforestry system can unite two factors in the dynamics of society: sustainable production and biodiversity protection (Saborío, 2016). The results showed that the use of two or more crops and the incorporation of livestock activity are the most frequent practices. None of these practices were used in the Maíz – Apasco, while the MIAF - Apasco system reported three of the four practices (Figure 4).

Economic scope

The rural viability function considers that a production system is viable when it offers attractive options that motivate the producer to persist in that area; part of this attraction involves a guaranteed employment and income (Ruiz *et al*., 2016). The results showed that 75% of the systems generate temporary employment for the family. The Maiz - Frutal Huautla system generates a constant family employment. Finally, the MIAF - Apasco system generates constant employment for both the family and external employees, resulting in a greater multifunctionality in the system and a positive impact on society.

The function of strengthening the local economy takes into account the integration of products in the local market where the system is developed. The greater the placement of products in the local market, the greater the multifunctionality (Ruiz *et al*., 2016). In this regard, the whole production of 50% of the systems is only used for self-consumption; in 12.5% of the systems, the totality of the production is distributed outside the locality of origin; in 12.5%, the totality of the production is distributed within the locality of origin;

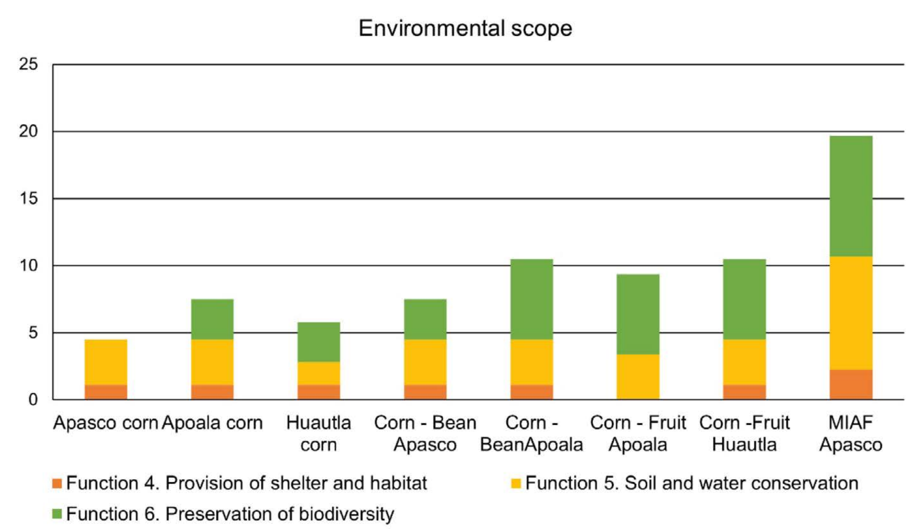

Figure 4. Accumulated value of functions for the environmental scope by system.

and, finally, 25% of the systems have a shared distribution of production (within and outside the locality of origin).

Regarding the food security function, diversified production systems that favor self-consumption provide greater food security, either through the direct consumption of products provided by the system or indirect consumption of other products in livestock subsystems (Urquía-Fernández, 2014; Ruiz *et al.*, 2016). The results showed that, in 87.5% of the systems, direct self-consumption is favored by the system manager, while both types of self-consumption were registered in only 12.5% of the systems (Figure 5).

Social scope

The protection of cultural heritage function considers the preservation of the lore regarding the cultivation of the land; therefore, it is directly related to the knowledge of the person responsible for the management of each system (Ruiz *et al.*, 2016). Farmer lore is linked to the reality of rural communities and has enabled the production of staple food for subsistence under different conditions. The results reflected that 62.5% of the systems usually produce in adverse environments (temperature and/or land slope), while 50% use different crops at the same time and in the same space. Two systems still make use of wild plants and/or animals for medicinal purposes. Only one system does not use chemical inputs or machinery and relies on ecological interdependencies to prevent pests and diseases.

The deep-rootedness function refers to the sense of belonging that the producers have towards the system they manage and the appreciation will be greater if they own the land where the system is developed and if they were born in the locality. All of the systems are managed by local land-owners.

Finally, the social cohesion function recognizes that there is a network of social actors (ejidos, associations, etc.) who seek to develop the countryside. This function considers the level of integration of the system manager. The results show that, although 100% of the

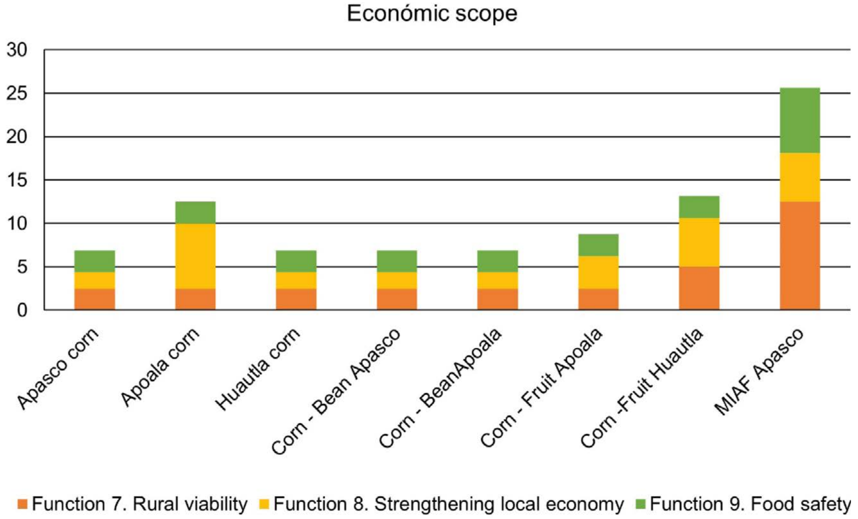

Figure 5. Accumulated value of functions for the economic scope by system.

systems are developed by producers who belong to a social group, only 50% attend the meetings and only 25% have a say in local matters (Figure 6).

IMSPA Integration

Once all the functions were analyzed, the value for each scope was determined. Subsequently, those values were added and the Multifunctionality Index of Agricultural Production Systems (IMPSA) was integrated (Table 3). The results showed that two of the five categories managed by the IMSPA were not represented in any system: category I (low-multifunctionality system) and category IV (with medium-high multifunctionality system).

Category II (medium-low multifunctionality systems) included the Maíz - Apasco, Maíz - Apoala, Maíz - Huautla, Maíz - Frijol Apasco, and Maíz - Frijol Apoala, which accounted for more than 50% of the systems. Figure 7 shows that the territorial and social scopes were the best represented functions, in contrast with the environmental and economic scope functions. These systems are developed in places where the producers own the land and constantly practice conventional agriculture, always growing the same number of crops per harvest.

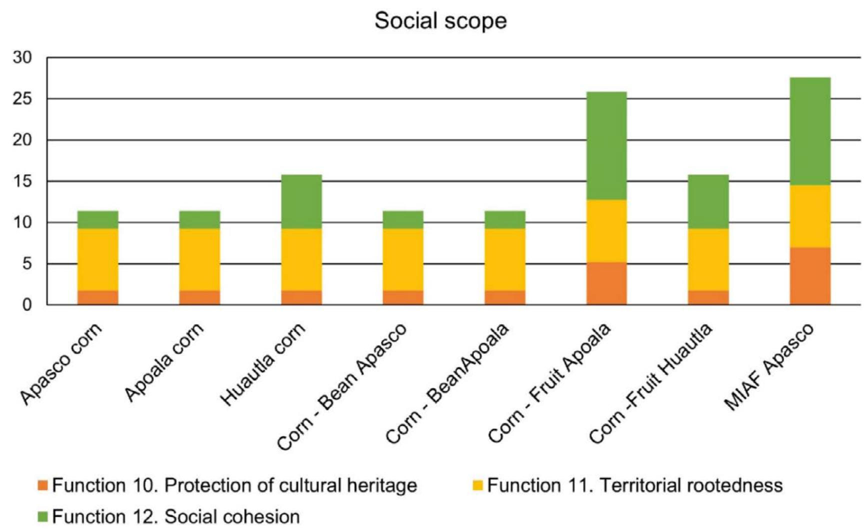

Figure 6. Accumulated value of functions for the social scope by system.

Table 3. IMSPA integration.

System	Territorial (20)	Environmental	Economic	Social (25)	IMSPA (0-100)	Category
Apasco corn	7.61	4.491	6.875	11.4375	30.4135	II
Apoala corn	7.61	7.491	12.5	11.4375	39.0385	II
Huautla corn	7.61	5.808	6.875	15.8125	36.1055	II
Corn-Bean Apasco	10.56	7.491	6.875	11.4375	36.3635	II
Corn-Bean Apoala	9.36	10.491	6.875	11.4375	38.1635	II
Corn-Fruit Apoala	10.56	9.366	8.75	25.875	54.551	III
Corn-Fruit Huautla	9.36	10.491	13.125	15.8125	48.7885	III
MIAF Apasco	14.65	19.665	25.625	27.625	87.565	V

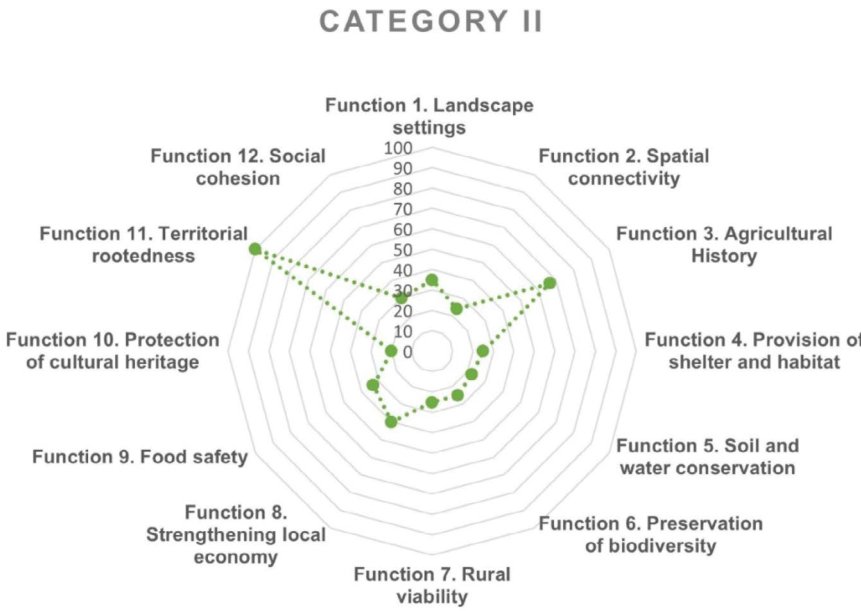

Figure 7. Representation of the average system with medium-low multifunctionality.

Category III (intermediate multifunctionality systems) was only represented by the Maíz - Frutal Apoala and Maíz - Frutal Huautla systems, which obtained an IMSPA of 54.551 and 48.7885, respectively. The production of these systems' functions is vulnerable to improvements or setbacks; therefore, it is worth highlighting the need to tip the scales in favor of an increased multifunctionality. The systems in this category contributed to all the evaluated functions. However, the functions of the territorial, economic, and social scopes make a bigger contribution than other functions (Figure 8).

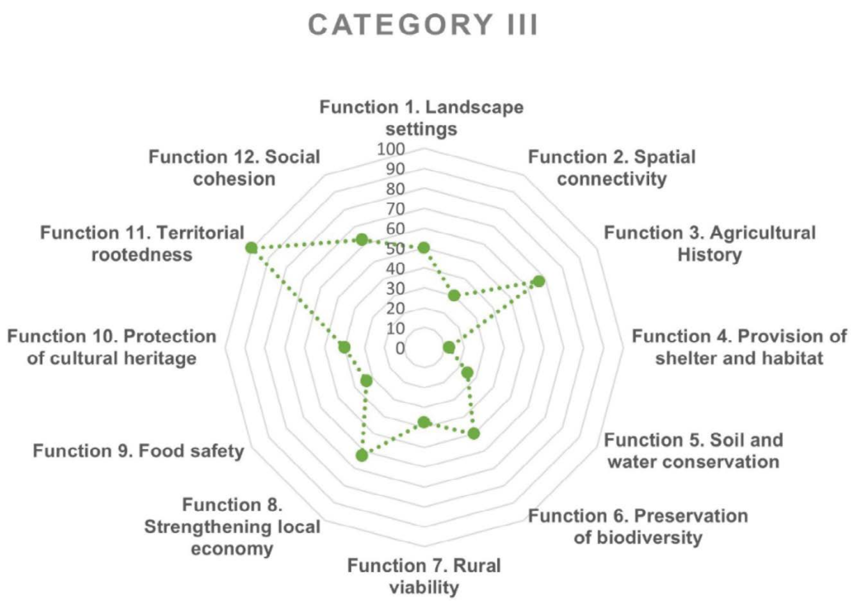

Figure 8. Representation of the average system with intermediate multifunctionality.

Finally, only the MIAF Apasco system was classified in category V (high multifunctionality systems), which shows that it is the only system that is effectively performing various functions. The multifunctionality in this system is not fully equitable in all scopes; nevertheless, an increase in the functions of the environmental scope was indeed observed. None of the other systems evaluated included this scope (Figure 9).

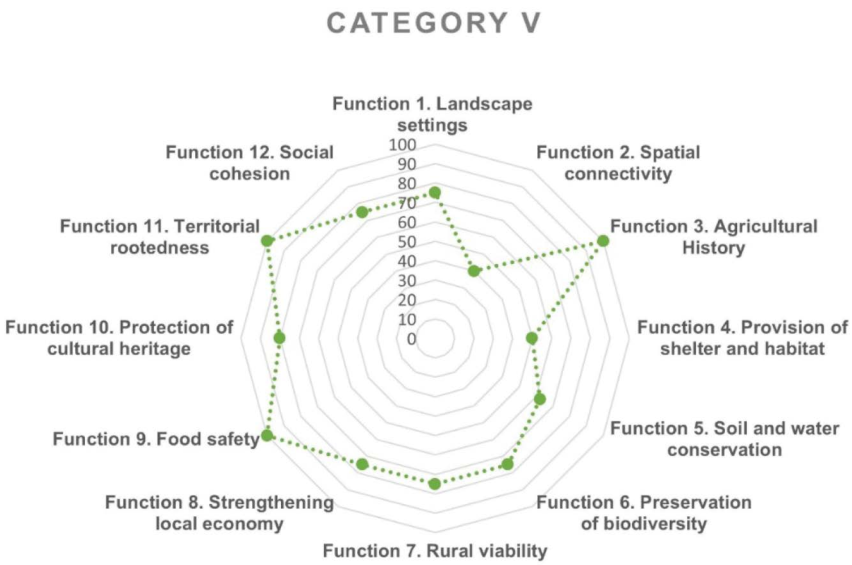

Figure 9. Representation of the average system with high multifunctionality.

CONCLUSIONS

The multifunctionality in maize productive systems can be extremely interesting for the inhabitants and producers of these communities. Their role and performance in their plots are fundamental. The MIAF-Apasco system is a clear example of how committed producers can transform a conventional agricultural practice into something more diversified and multifunctional. Nevertheless, a real change requires time, dedication, effort, and a lot of motivation. Hence the importance of understanding agriculture as a multifunctional activity that can contribute to the progress or to strengthen the arrangements that enable the maintenance or improvement of rural development. The implementation of a multifunctional agriculture makes a positive contribution to the partial achievement of the global sustainability objective. However, we must highlight the difference between both terms: while sustainability guides the objectives, multifunctionality is a characteristic of the agricultural production process. The IMSPA enters the theoretical and practical debate on the multifunctionality of agriculture. This article exposes the capacity of the IMSPA as a tool to analyze productive systems, evaluating the degree of multifunctionality that they generate. The index can be used to monitor the multifunctionality of the systems over time, favoring decision-making that encourages a management that promotes sustainability in the agricultural field.

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