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Implementing the nature's contributions framework: A case study based on farm typologies in small-scale agroecosystems from the Mexico highlands

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Introduction: Integrating the heterogeneity of small-scale agriculture with the regulation, material, and non-material contributions is key to complementing the rural-support policy instruments. The objectives of the present study were to analyze the diversity of agricultural types of management in small-scale maize agroecosystems and discuss their implications for nature's contributions in the region of Valles Altos, México.

Methods: The methodology was conducted by constructing an agricultural management typology with multivariate statistical analysis for 112 small plots interviews. The operationalization of regulation, material, and non-material nature's contributions was based on the definition and counting of cultural elements from agronomic management for each class of contribution.

Results: The results indicate three different types of agricultural management defined mainly by the type of seed, the destination of harvest, and the type of tillage. This management diversity is guided by farmers' motivation to achieve food self-sufficiency or generate income from grain sales. Each management type has a unique provision of regulation, material, and no material contributions defined by the use of the native seed, use of stover, and management diversification.

Discussion: The integration of farm typology methods and nature's contributions framework reveals that it is critical to establish new incentives that include the biological and cultural diversity of agroecosystems and the individual motivations of farmers. This may help conserve the natural and cultural values of agriculture and design appropriate incentives for small-scale agriculture.

KEYWORDS

small-scale agriculture, policy, maize, *MasAgro*, Mexico

1. Introduction

Agroecosystems are socio-ecological systems widely known as sites that provide ecosystem services (Swinton et al., 2007; Potschin-Young and Haines-Young, 2011) and are closely related to ecological conservation and social welfare (Tomich et al., 2011; Eakin et al., 2015; Tenza et al., 2017). The knowledge of small-scale farmers reflects important sustainability principles such as resilience, autonomy, and self-sufficiency

(Palestina-González et al., 2021). Integrating the socio-ecological approach to managing agroecosystems and proposing new sustainability evaluation frameworks is possible if performance indicators recognize areas of sustainability such as social welfare, food security, and biocultural heritage (Tomich et al., 2011; Eakin et al., 2015; Tenza et al., 2017). The Nature's Contributions to People (NCPs) conceptual framework (Díaz et al., 2018) is based on and has similarities to Ecosystem Services (ES) (Daily and Matson, 2008; Potschin-Young and Haines-Young, 2011). The main difference is that the NCPs conceptual framework focuses on the central role of culture in defining contributions, human relationships, and knowledge of socio-ecological systems. Likewise, it considers contributions' actual and potential provisions under a co-production approach. At the same time, research based on ES focused on ecological functions that provide benefits without considering the role of people in providing (Díaz et al., 2018). This proposal eliminates the utilitarian vision of nature because it gives the same level of importance to material and non-material aspects of socio-ecological systems (Díaz et al., 2018; IPBES, 2019). This is an opportunity to reconcile visions between agricultural production and conservation; the NCPs recognize the central role of the co-production of benefits without neglecting the importance of agriculture's productive and monetary benefits.

The traditional Mexican agricultural system is the *milpa* (from the Nahuatl *milpan* "plot planted on top of"), a polyculture with maize as the main crop accompanied by beans, pumpkins, chili peppers, or tomatoes; in addition to herbaceous plants that grow naturally and are known as *quelites* (Hernandez-Xolocotzi, 1988; Aragón-Cuevas et al., 2005). The native varieties of the species cultivated in these traditional systems are the product of knowledge, technology, and agricultural practices that sustain the food sovereignty of peasant families and Mexican cuisine [Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2020]. Maize agroecosystems in polyculture or monoculture are considered to constitute the habitat of the genetic diversity of maize, and it is where the 64 native maize races known in Mexico are cultivated [Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2020]. Beginning in 1940, agricultural improvement began on small properties (<5 ha) where farmers were organized and had access to credits (Hernandez-Xolocotzi, 1988). Farmers and agrarian communities adapted new technologies such as fertilizers, tractors, and seeds during this time. Over time, this generated a high variability of new agroecosystems, ranging from large-scale, highly industrialized systems in the north of the country; to less industrialized small-scale systems concentrated in the center and southeast (Alvarez et al., 2014). Boege (2008) point out that agroecosystems are productive systems where ecosystems and cultural traditions are conserved. The government's responsibility must be channeled toward conserving agricultural fields, germplasm, and farmers' knowledge.

Understanding the heterogeneity of management practices and farmers' preferences can help define proper incentives and adjust policies to the socio-ecological context of agriculture (Antoni et al., 2019; Jaleta et al., 2019; Ratna-Reddy et al., 2020). Farm typologies are a way to capture, summarize, and understand the variability of farms (Alvarez et al., 2014). Typologies are constructed from individual numerical and categorical variables highly accurate because they are recorded at plot scale (Bhattarai et al., 2017), and the results are interpreted within a broader context because it categorizes groups of plots and types of producers (Guarín et al., 2020; Hammond et al., 2020; López-Ridaura et al., 2021; Santos et al., 2021). For this reason, farm typologies help develop interventions and guide appropriate policy approaches. In small-scale agriculture, crop management partly results from decisions made by individual farmers regarding the type of incentives, technology, and inputs applied to production (Alvarez et al., 2018; Santos et al., 2021). All farmers have different needs, interests, and objectives (Davidova et al., 2012); in addition, the biophysical, institutional, social, and economic contexts can be largely heterogeneous between localities or regions, so each farmer responds differently to these drivers of change (Alvarez et al., 2014; Pinto-Correia et al., 2021).

The National Development Plan (PND) is the highest-ranking political instrument in Mexico; it defines small-scale as agricultural production of up to 0.2 hectares with an irrigation system and up to 5 hectares of rainfed land (Gobierno de México, 2020). Small-scale agriculture is a priority for the national economy because it represents 54% of food production and 80% of contracted and paid employment (Gobierno de México, 2020). Production is mainly for self-sufficiency, and the main crops are maize, sugar cane, coffee, beans, and squash, concentrated in the country's central region (Gobierno de México, 2020). Maize cropping has a wide distribution throughout the territory. Its biological diversity is linked to management practices, with more than 59 native maize varieties grown in small-scale systems (<5 ha) (Bellon et al., 2018, 2021). This biological and cultural diversity of maize agriculture is represented in rural policy programs protecting maize diversity and the milpa system, with the "Ley Federal para el Fomento y protección del maíz nativo" (Federal Law for protection and promotion of native maize) (Diario Oficial de la Federación, 2020). In other initiatives, the government promotes economic and material incentives through payments and fertilizer distribution with programs like *"Fertilizantes para el bienestar"* (fertilizers for welfare) (Gobierno de México, 2022). The lack of information regarding the high diversity of agricultural management types in Mexico and their relationship with contributions to people hinders the inclusion of biological and cultural diversity in national and international sustainability policies (Piñeiro et al., 2020).

Despite the versatility of farm typologies (Ragkos et al., 2017; Alvarez et al., 2018) and the wide biological and cultural diversity in maize agriculture in Mexico (Acevedo et al., 2011; Bellon et al., 2021), the application of typologies to assess agroecosystems' contributions to people or inform agricultural policies have been scarce and limited to the center and Southeast of the country, however, some studies address water resource conflicts (LaFevor et al., 2021), economic productivity (Zepeda-Villarreal et al., 2020), and to document farmers' perspectives (Novotny et al., 2021). The objectives of the present study were to analyze the diversity of agricultural management in small-scale maize agroecosystems and discuss its implications for the provisioning of NCPs in the highlands of Mexico. The methodological approach is based on integrating the social-ecological system (SES) and NCPs frameworks. It can be replicated in other social-ecological contexts to recognize the influence of management on the contributions, agricultural production, and wellbeing of farmers' families. This study proposes that agroecosystems' management practices, inputs, and elements can be operationalized and interpreted as regulation, material, and non-material indicators under the NCPs framework.

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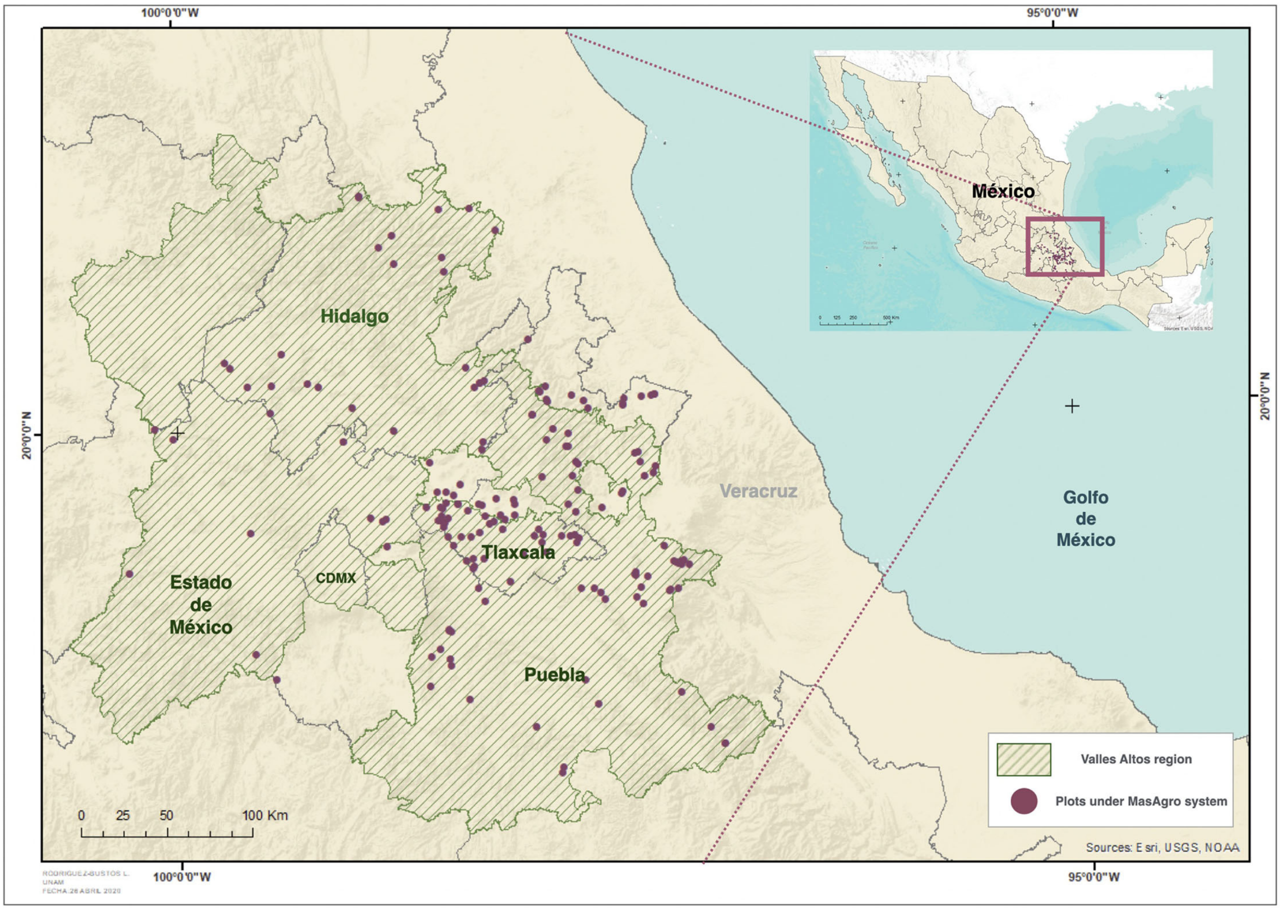

FIGURE 1
Location map of Mexico highlands. The Mexico highlands region states are shown in green; the plots considered in this study are marked purple.

2. Materials and methods

2.1. Case of study

Mexico highlands is a geomorphological region characterized as a central highland with an altitude between 2,200 and 2,600 (m.a.s.l), surrounded by a mountainous volcanic area with natural temperate forest ecosystems. The climate is temperate-humid, with precipitation concentrated between May and September (Bobbink et al., 2003). In this area, the stratovolcanoes Iztaccíhuatl (5,220 m a.s.l.), Popocatépetl (5,450 m a.s.l.), and Matlalcueye (4,461 m.a.s.l.) dominate the landscape (Bobbink et al., 2003). The prevailing soil type is Andosol developed over pyroclastic fall materials such as tephra, ash, and pumice [World reference base for soil resources (WRB), 2015]. The region comprises parts of the states of Estado de Mexico, Hidalgo, Tlaxcala, and Puebla in the center of the country (Figure 1). The area is densely populated and located in the vicinity of the capital city of Mexico. The surrounding area is highly populated, and industry, forestry, and agriculture are practiced in areas once covered by temperate mountain forests dominated by pines and oaks (Rodríguez-Bustos et al., 2022a). In addition to agriculture, food processing and packaging activities predominate (INEGI, 2010). Mexico highlands was the third largest region included in *MasAgro* (*Modernización Sustentable de la Agricultura Tradicional,* Sustainable Modernization of Traditional Agriculture), which was a public policy program to promote sustainable intensification in Mexico through technical guidance on the selection of farming technologies Secretaría de Agricultura y Desarrollo Rural (SADER), (n.d.); Turrent-Fernández et al., 2014; Centro Mexicano de Derecho Ambiental (CEMDA), 2016; Centro Internacional para el mejoramiento del Maí-z y el Trigo (CIMMYT), 2020.

MasAgro offered farmers a technological menu that included specific management practices such as fertilization diagnosis related to soil nutrients analysis before the agronomic cycle started, integral fertilization associated with a complete scheme of recommendations for fertilization, conservation agriculture, market diversification, and seed availability [Centro Internacional para el mejoramiento del Maí-z y el Trigo (CIMMYT), (2012)]. It was launched in 2010 and ended in 2020, primarily supported by public funds from the Board of Agriculture and Rural Development of Mexico and private donors [Secretaría de Agricultura y Desarrollo Rural (SADER), (n.d.); Centro Internacional para el mejoramiento del Maí-z y el Trigo (CIMMYT), 2020]. The implementation of *MasAgro* in the region represented an opportunity to test the operationalization of a conceptual framework through its elements and actors because all agricultural plots analyzed in this investigation are located within the same geographic area and are managed according to a standard policy instrument through which they have been characterized. The

112 plots use maize as a major food crop, have an average farm size of 1.68 ha, and the land property is ejido or private (Table 1). The ejido in Mexico is one of the modalities of land tenure, it refers to a type of agrarian social property. Its configuration is historical because its objective was to restore agricultural land to peasants during the revolutionary period. In this type of property, tenure is collective and is regulated by an ejidal assembly, which is the command center in which the decision-making process is concentrated [Centro de Estudios Sociales y de Opinion Publica (CESOP), 2019].

2.1.1. General methodology

The interpretation of contributions is based on the conceptualization of *Mexico highlands* as a social-ecological system (SES). The key elements are three social-ecological interactions: policy programs, *in-situ* agricultural management, and NCPs (Rodríguez-Bustos et al., 2022a). The general methodology for this investigation is presented in Figure 2, describing data sources and products. The first data source was the semi-structured interviews performed by *MasAgro* technicians in the field and registered at the plot level between 2016 and 2019. The interviews contain detailed information about agricultural management, which was used to perform a farm typology, and a farmer profile for each farm typology. The second data source was the workshops conducted by the research team with farmers and partners of the International Center for Maize and Wheat Improvement (CIMMYT) in in-person and remote meetings between 2019 and 2021, respectively. The main objective of the workshops with CIMMYT partners was to operationalize the NCPs framework by defining a set of management practices that can be interpreted as regulation, material, or non-material contributions. The operationalization was used to identify each management type's contributions. Workshops with the farmers were attended to validate the selection of contributions. The group of ten farmers for the workshops was made up of men between the ages of 45–65, with high school as the highest level of studies and Spanish as their only language. The sections below describe in detail each step of this general methodology.

TABLE 1 Biophysical and agronomic characteristics of agricultural plots in Mexico's highlands.

Characteristic	Mexico highlands
Biophysical	
Altitude (m a.s.l.)	1,500–2,500
Annual precipitation (mm)	700–800
Dominant soil type (FAO)	Andosol (volcanic)
Agronomic	
Average farm size (ha)	1.68
Major food crop	Maize
Land property	Private and Ejido

2.1.2. Data source

Access to the data for this investigation was established through a collaboration agreement between CIMMYT partners and the research team. The data source for the construction of farm typologies was a set of semi-structured interviews put together in what was called by the program officers "*bitácora*

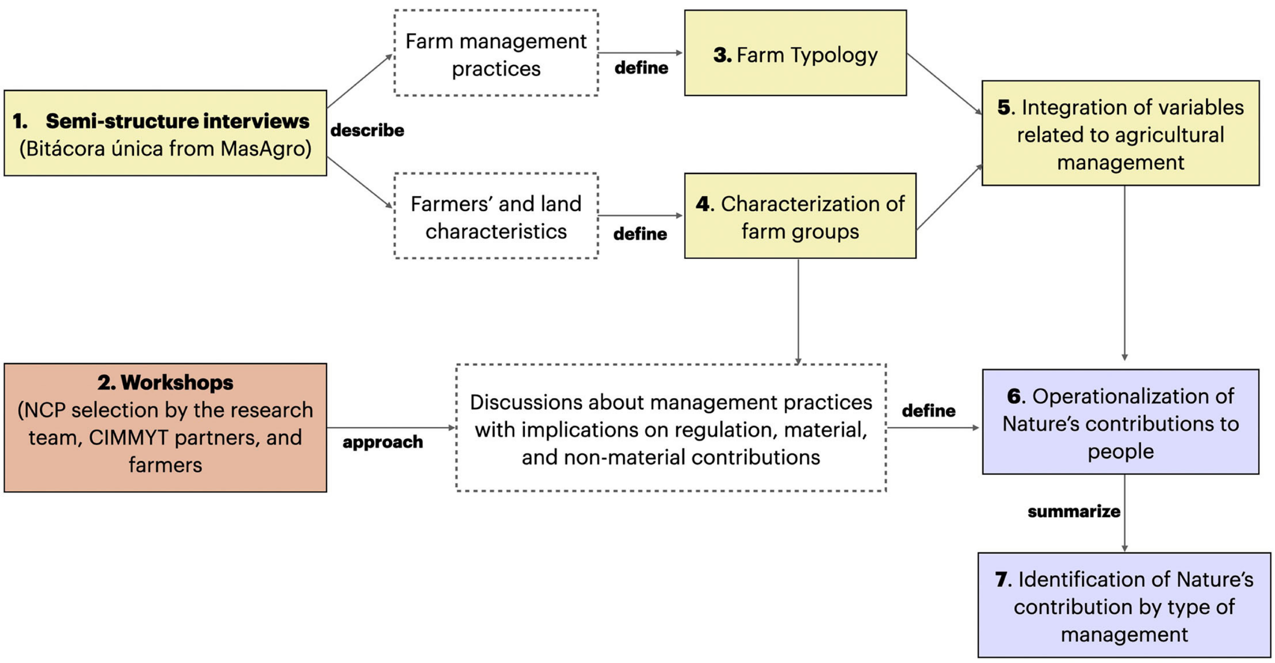

FIGURE 2
General methodology in this study. The data sources are marked with numbers 1 and 2, the boxes with solid lines and numbers indicate methodological steps, and the numbers indicate the order of the methodology. The boxes with dotted lines indicate elements of interest in each step.

única," a log book used by field technicians from the program to keep a record of all data related to a single plot. MasAgro technicians applied these interviews between 2016 and 2019. They included 50 open and optional questions organized into four topics: farmer's information, property description, technological menu, and agronomic management (Supplementary Table 1). Questions were aimed at obtaining information about plot localization, harvest destination, agronomic management, soil management, tillage, fertilization, irrigation, pest control, insecticides, crop rotation, and crop varieties as indicators of management practices. In total, 112 plots of rainfed maize for the spring-summer cycle with complete information were analyzed [Centro Internacional para el mejoramiento del Maí-z y el Trigo (CIMMYT), (2012)].

The farm typology was built based on the methodology proposed by Alvarez et al. (2014), summarized in three steps: (i) selecting the variables that define the typology based on a heterogeneous set of variables associated with agricultural management practices, (ii) recognizing the importance of each variable on the separation of management types, and (iii) describing the classified management types. The main objective of this typology was to organize agricultural management information to evaluate the provision of contributions by type of management. In this case study, most agricultural practices' heterogeneity was given at the plot scale. Therefore, plot-based numerical and categorical variables were selected to build the typology (Table 2). This set included variables reported for all 112 plots in the "*bitácora única*" and could be interpreted under the conceptual framework of NCPs.

TABLE 2 Variables for farm typology.

Variable	Description	Units or categories
Fertilizers	Fertilization intensity	kg/ha
Seed	Type of seed	Native, open-pollinated variety, or hybrid
Tillage	Type of tillage	Manual or mechanical
Residues	Use of CROP residues	Sale, stover
Yield	Productivity per farm	tons/ha
Harvest use	Type of use	Sale, food self-sufficiency, or both
Food self-sufficiency	Amount of the harvest used for self-sufficiency	kg
Land property	Land tenure	Ejido or private

The second step was establishing the relationship between the type of management and NCPs. This step is expressed through a presence/absence table that classifies the operational variable for each management type. Finally, the contribution level per management type was classified as low, regular, or high according to the percentage of farms with the presence of the operational variable for every contribution.

2.1.3. Statistical analysis

The methodology of Alvarez et al. (2014) was performed using factor analysis of mixed data (FAMD) to reduce the dimensions of interest. The main strength of the methodology proposed by Alvarez et al. (2014) is that it allows summarizing heterogeneous information from different management systems, FAMD allows giving the same importance to the numerical and categorical variables of agricultural management because it does not separate the data for treatment (Alvarez et al., 2018; Sinha et al., 2022). Based on the coordinates of each plot in the FAMD, a cluster analysis of agricultural management types was carried out using the NbCluster algorithm. Significant differences between the management types were determined using a similarity analysis (ANOSIM). Statistical analysis and figure drafting were conducted in R and Python. The anonymized database and scripts used are available in the GitHub repository.

2.2. Operationalization of Nature's Contributions to People framework

The operationalization of NCPs was divided into two steps; the first one implies the selection of operational variables from the agricultural management related to contributions. In this step, the selected variables for each category were defined with the responses of *MasAgro* partners, three groups of farmers participating in *MasAgro*, and the input of four university academic scientists in the area of Sustainability Science (Table 3). According to the IPBES (2019) conceptual framework, NCPs were classified into regulation, material, and non-material.

3. Results

3.1. Farming systems in Mexico highlands

The FAMD constructed from agricultural management variables accounted for 40% of the data variability in the first two dimensions (Figure 3). Harvest use, type of tillage, and seed type separate the data in the first dimension (DM1) of the FAMD and explain 23.5% of the variance (Figure 3). Harvest use explains 24.5% of the variance in DM1. It refers to the destination of the crop, which is either sold to the tortilla industry or used for food self-sufficiency for farmers and their families, and, in some cases, for both purposes. The type of tillage accounts for 26% of the variance in DM1; tillage is manual when only simple tools and human force are used; animal tillage refers to a conventional plow pulled by cattle, and mechanical tillage refers to tractors or threshers used for cleaning and harvesting. Seed type accounts for 18.5% of the variance in DM1 and refers to native, hybrid, or open-pollinated variety seed planting. Native seed is a farmer-owned maize variety stored during the previous agricultural cycle; the hybrid seed is a trademark sold as agricultural input by seed companies, intended for yield stabilization purposes; improved seed still lacks a trading name because it is in the experimental phase. The second dimension (DM2) of the FAMD explains 15.9% of the total data variability. In DM2, plant residues as stubble and plant residues for sale in packages are the main variables that separate the data. The variable use of residues as stubble accounts for 40.2% of the variance. It refers to maize residues as organic fertilizer and a protective layer to prevent soil erosion and moisture retention. Using crop residues for sale accounts for 40.6% of the variance and refers to the sale of forage for livestock (Figure 3).

In Figure 4, plots are shown colored according to three variables to illustrate the reduced dimensions of the FAMD. Concerning seed type, native seeds (green) represent 60% of plots in Mexico highlands;

TABLE 3 Participants for the selection and validation of nature's contributions.

Focus of participation	Category	Description	Number of participants
Validation	Farmers	Three focal groups at the municipalities of Piedra Canteada, Sanctorum y Nanacamilpa	10
Selection	International agencies	Technician, HUB manager, and scientist from CIMMYT	4
	Research team	Academic team in this research	4

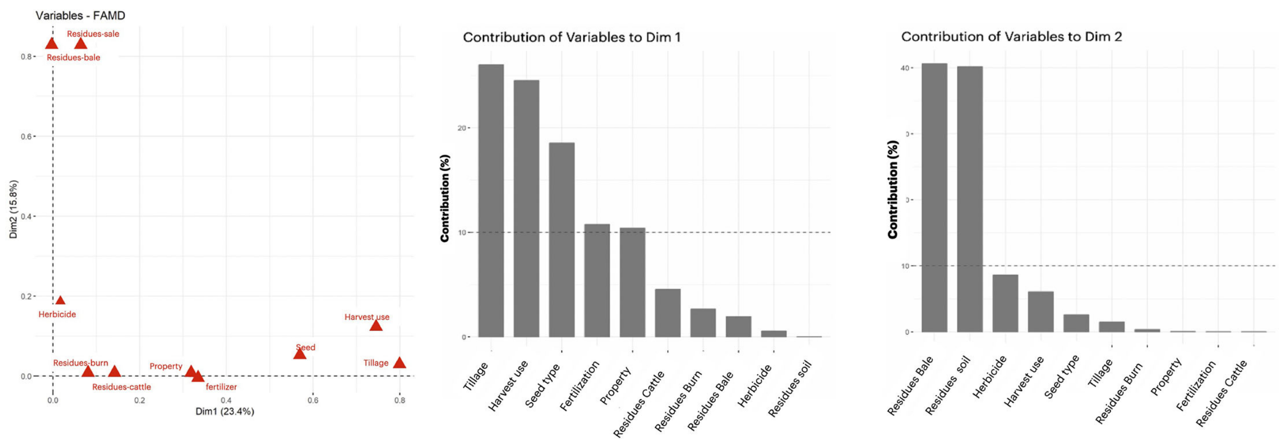

FIGURE 3
The graph on the **(Left)** shows the coordinates from the variables that construct the FAMD. The main variables in DM1 (23.5%) are tillage, harvest use, and seed type. In DM2 (15.9%), the main variables are the use of crop residues for sale or use as bale. The weight (%) of variables in each FAMD component is shown in the **(Central)** graph for DM1 and on the **(Right)** for DM2.

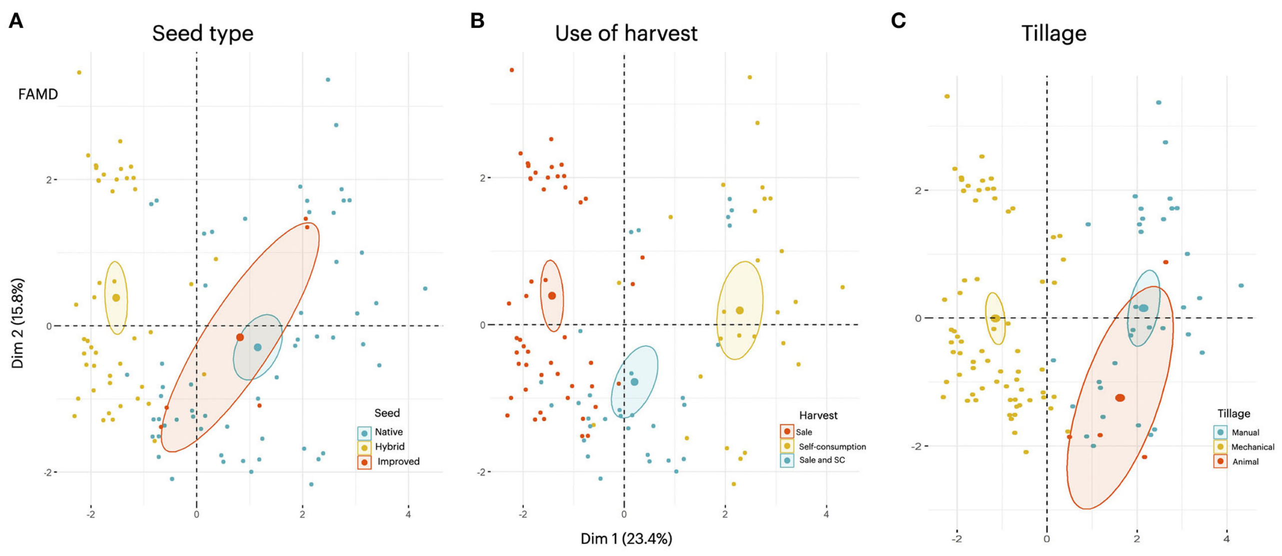

FIGURE 4
FAMD for farm typologies. Graphical representation of Mexico highlands plots and their distribution, showing each plot according to the type of property **(A)** seed type, **(B)** use of the harvest, and **(C)** type of tillage. Each dot corresponds to one plot in the field; the color of the dots highlights the categorical variable in the legend; ellipses correspond to confidence ellipses around the mean.

improved variety (red) is used by 5% of farmers; hybrid seed (yellow) is used by 35% of farmers (Figure 4A). Then, concerning harvest use, food self-sufficiency (yellow) is practiced by 45% of farmers; harvest for sale (red) is practiced by 26.5% of farmers; and mixed-use (green), characterized by selling the crop and storing it for food self-sufficiency, is practiced by 28.5% of farmers in the region (Figure 4B). The last variable, tillage, shows that mechanical tillage (yellow) is used by 85% of farmers, manual (green) is used by 10% of farmers, and animal tillage is used in 5% of plots (red) (Figure 4C).

The cluster analysis from NbClust results in three clusters that describe the number of management types in Mexico highlands (Figure 5A). The similarity analysis (ANOSIM) shows that the variance between the clusters is greater than the internal variance in each one (Figure 5B). Results show three groups of plots that are statistically different, each corresponding to a type of management ($R = 0.85$; $P = 0.001$).

The results from farm typology classification show that type one comprises 46% of the plots where more than one-half of farmers sow the hybrid seed and sell the grain to the tortilla industry; 50% of farmers in this cluster save an average of 408 kg of grain for the family food self-sufficiency and use residues for stubble. Type two comprises 29% of the plots and is characterized by conservation-oriented traditional agriculture; 100% of farmers in this cluster sow native seed, apply manual tillage, and practice food self-sufficiency and diversification of practices. Farmers store an average of 1 ton of grain for food, which meets their annual consumption of maize. Diversification of agricultural practices is observed in residue management because it is allocated for use as stubble, feed for cattle, and sold as bales. Type three accounts for 24% of the plots and is characterized by industrial agriculture for maize grain marketing. All farmers in this cluster plant a hybrid seed, apply mechanical tillage, use the residue for stubble, and sold as bales. Fertilizers and herbicides are widespread in *Mexico highlands*, with 95% of plots using them, no matter the type of management, but types one and three use twice the amount of fertilizer as type two. Regarding herbicides, type three uses twice as much as types one and two. In terms of yield, types one and three double the yield of type two (Table 4; Supplementary Table 1).

3.2. Nature's contributions

Table 4 shows the operationalization of NCPs in *Mexico highlands*, the first and the second row present the general classification of contributions in regulation, material and non-material, and the names of contributions according to IPBES (2019). The operational indicator refers to a management element selected to evaluate the presence or absence of each contribution. The table also briefly describes the importance and interpretation of each operational indicator for NCPs. The regulation class was represented by the protection of soils and habitat creation contributions, and the operational indicators were the use of the native seed. The management of vegetal residues as stover to cover the soils until the next agronomic cycle. The material contributions were represented by two elements, food and feed. Food is related to the material resources produced in the agroecosystems sold to the tortilla market; in this case, the operational indicator is the presence of yield. Feed is related to the material resources produced in the agroecosystems used for the self-sufficiency of the farmer's family. The non-material contributions were represented by Supporting identities, defined as a contribution related to the cultural heritage of farmers. The operational indicators selected were a native seed, manual labor of the land, and management diversification.

The results of NCPs operationalization show that each management type has different levels of contributions (Figure 6). Type 1, compared to types 2 and 3, is a regular contributor to all regulation, material, and non-material contributions. Type 2 is the highest contributor to habitat creation, feed, and supporting identities; but is the lower contributor to the protection of soils and

TABLE 4 Integration of management, farmers' profile, and plot characteristics.

Farm type	Characterization of management, farmers' profile, and plot characteristics
Type I	The management is intensive, characterized by the use of synthetic fertilizers, mechanized tillage, use of stover, and mainly hybrid seeds.
	All farmers are dedicated to agriculture as economic activity, they sell maize for the tortilla industry. Half of the farmers sow native seeds and store the maize for food self-sufficiency.
	The land is in a communitarian property called ejido, and the size of plots is bigger in comparison with types two and three.
Type II	The management is of conservation agriculture, characterized by the use of native seeds, synthetic fertilizers, less intensive than the other types, and manual and animal tillage.
	All farmers are dedicated to agriculture for food self-sufficiency and a quarter part of them also use maize for sale.
	The land is private property, and the size of plots is smaller in comparison with the other types.
Type III	The management is intensive, characterized by mechanized tillage, the use of synthetic fertilizers, and hybrid seeds.
	All farmers are dedicated to agriculture as economic activity and sell their maize for the tortilla industry. Less than 10% of farmers also use native seeds, use maize residues to feed cattle and sell maize residues in a bale.
	The land is in a communitarian property called ejido, and the size of the plots is medium in comparison with types one and two.

food. Type 3 is the highest contributor to the protection of soils and food but is lower for habitat creation, feed, and supporting identities. From a socio-ecological perspective, the results of NCPs reveal the elements of agricultural management related to a particular class of contributions.

4. Discussion

4.1. Farm diversity

The farm typology indicates that in *Mexico highlands*, management practices separate farmers with different use of harvest and probably different socioeconomic histories. The seed type, type of tillage, and harvest destination defined the three types of management. This suggests that the heterogeneity is partly driven by the motivation of reaching food self-sufficiency or earning an income from harvest sales. Some studies highlight the remarkable heterogeneity in farmers' decisions related to incentive programs (Hasler et al., 2019), mainly promoted for incentives that do not count the heterogeneity of practices (Kaiser and Burger, 2022). The FAMD reveals that the differentiation of management is likely due to the shared evolution of farmers with different goals or possibilities; this appears to be expressed by the type of seed because this variable

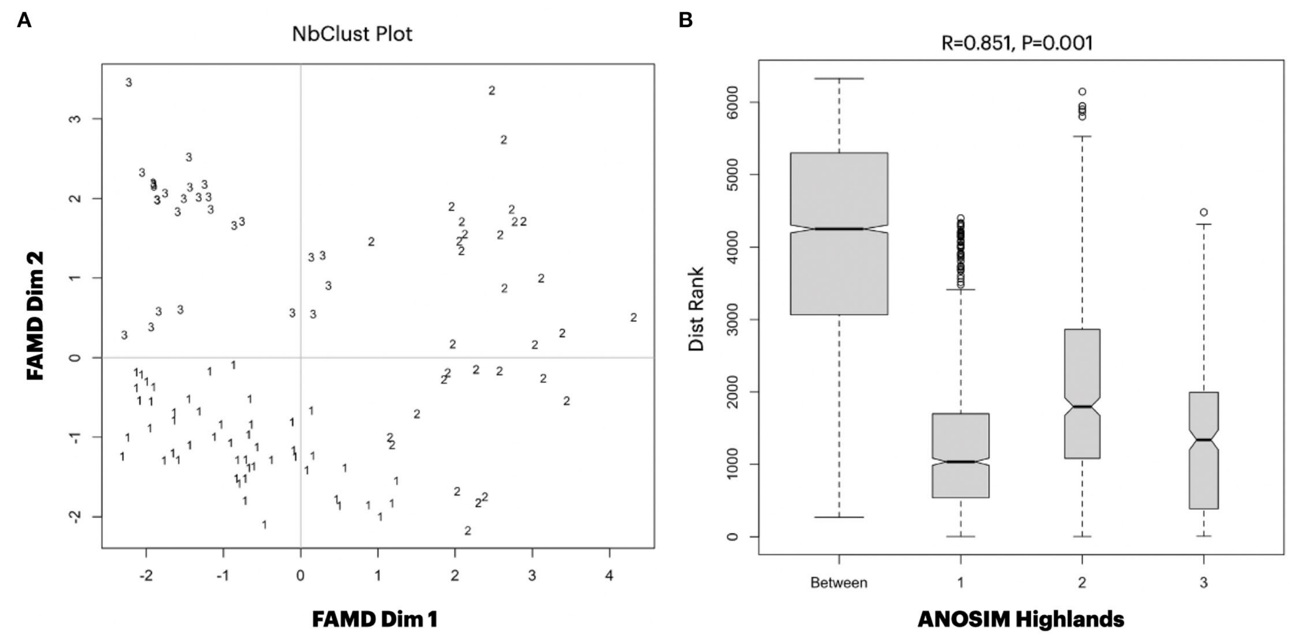

FIGURE 5
Similarity analysis for farm typology. **(A)** Shows the cluster analysis from NbCluster. Each plot is displayed according to its coordinates in the FAMD, with an assigned management type ranging from 1 to 3. **(B)** Shows the results of the significance test with ANOSIM. The ANOSIM X-axis shows the significant differences calculated between groups (between) and within each group (1, 2, and 3).

separate management affinities and defines harvest destination and type of tillage.

Individual practices such as fertilization or seed type in each management type are interrelated and can even be interpreted as a "bundle" of practices (Santos et al., 2021). In *Mexico highlands,* seed type was more important than yield as an indicator of production success. A high yield is essential for commercially driven agricultural management such as type three. In contrast, for management based on food self-sufficiency, such as type two, a lower yield is not critical as long as food demand is met and seeds are obtained for the next agronomic cycle. Pradhan et al. (2014) point out that yield and self-sufficiency should be viewed as supplementary indicators of food security benefits at the local, regional, and global scales because yield indicates physical accessibility to food, but self-sufficiency describes feeding affordability. Besides identifying different types of management, the farm typology emphasizes the importance of socio-cultural elements of agricultural management that go beyond yields, such as the importance of seed type, tillage, and the diversification of agricultural practices. The social aspects of management involve the prevailing attitudes toward farming, ideas about nutritional value, seed conservation mechanisms, and organized interests (Smith et al., 2010; Ingram et al., 2015). This is probably because farmers prioritize their decisions over any institutional scheme and define their management based on cultural preferences, even though political programs offer them other options (as is the case of *MasAgro*).

Agricultural management also represents an opportunity for farmers to establish cultural differentiation related to purchasing capacity (Warde, 2005; Kaiser and Burger, 2022). For example, selecting a seed type, either native or hybrid, reflects social relationships on a local scale or across scales (Santos et al., 2021). The exchange of native seed varieties between farmers indicates a local governance process, while the use of hybrid seed indicates multi-national trade transactions (across scales) (Gaventa, 2006; Martin-Lopez et al., 2019). Recognizing the type of social relationships also means recognizing power relationships (Gaventa, 2006). We suggest that management based on native seeds in *Mexico highlands* attain higher control of their sovereignty, and empowerment is based on community-based management of production inputs. While management based on hybrid seeds could be influenced by external factors like the market, seed price, access to seed, and their influence over seed price commercialization. Hernández et al. (2022) note that in *Chiapas Highlands*, agricultural practices based on the use of native seeds are conceived as a resistance and autonomy tool toward forms of power from outside the community; therefore, today and in the future, the use of native seed is a way to maintain political and economic autonomy. This suggests that the social relationships within a particular management system evidence the role of native seeds in the formulation of development projects in rural communities. For *Mexico highlands*, is necessary to identify how these power interrelations are regulated by formal institutions (laws and ejido), or informal institutions (habits and customs) (Martin-Lopez et al., 2019). This information may even influence the region's political and territorial scope programs.

Synthetic fertilization and herbicide were not crucial for farm typologies in *Mexico highlands* because both are widespread practices and are used in 95% of plots. This does not mean that fertilization is not an essential element; quite the contrary, because, in Mexico highlands, maize monocrops predominate, which is critical to minimize the use of synthetic fertilizers to ensure the sustainable transition of agriculture. One of the common issues of conventional agriculture is the tendency to over-fertilize based on the assumption that more is better than less (Hasler et al., 2019). In *Mexico highlands,* we found a synergy between fertilization intensity and seed type. For example, the fertilization intensity in type three (where farmers

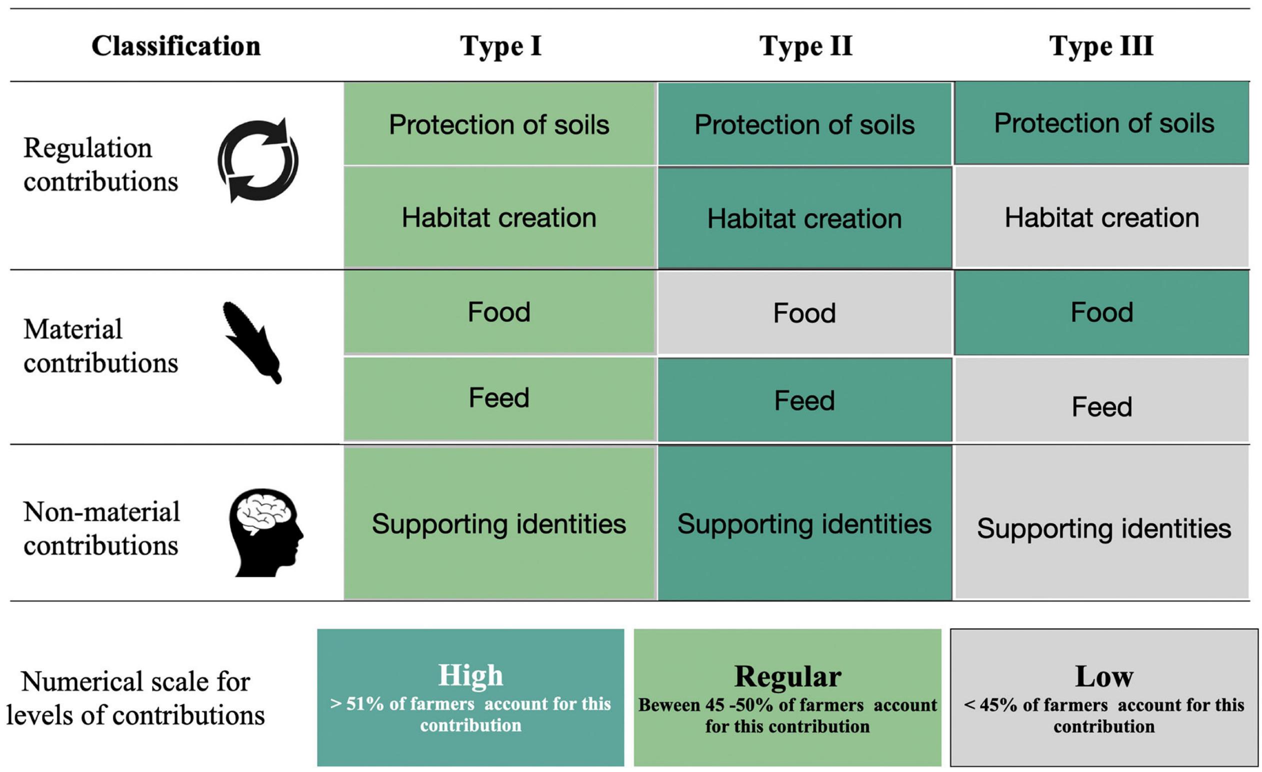

FIGURE 6
Nature's contributions in maize agroecosystem from Mexico highlands. The shades of gray show the level of contribution in the management types, the dark gray means a high level of contribution, light gray means a regular level of contribution, and white means a low level of contribution.

use exclusively hybrid seed) doubles the intensity of type two (with exclusive use of native seed). This is consistent with two case studies in Southeastern Mexico, where farmers planting native seeds are more labor-intensive and less agrochemical-intensive (Perales et al., 2005; Soleri et al., 2006). Unlike native seeds, fertilization is linked to the farmer's purchasing power (Hamid et al., 2021). Hammond et al. (2020) observed in small-scale maize systems in the African tropics that the management types use higher fertilizer when it is more accessible or affordable. In *Mexico highlands* there are high rates of fertilization. The interviews indicate that the widespread use of fertilizers is open to incorporating organic amendments, mainly because farmers recognize undesirable characteristics of synthetic fertilizers, such as increased production costs and the requirement to apply them at exact dates. The most crucial evidence of disagreement is that farmers use it less in crops intended for food, which in all cases involves native seed. This reality should be a wake-up call to Mexican authorities to modify incentive programs such as "*Fertilizantes para el bienestar*," based on providing synthetic fertilizers as incentives for crop production rather than promoting practices based on the conservation of ecological soil functions.

4.2. Nature's Contributions to People: A framework for wellbeing

The farm typology approach allowed exploring the relationships between policy, management, and contributions from two perspectives: the response of contributions to management practices and the coherence of agricultural management (Santos et al., 2021). The response of contributions to management practices refers to the impact—usually adverse—of management on biodiversity and loss of cultural heritage (Santos et al., 2021). In this study, the NCPs framework highlights the positive effect of management practices on soil protection, habitat, and supporting identities. Material contributions are the most important in agroecosystems because they represent food production. In agricultural landscapes, these contributions are indicators of food security because they distinguish the use of crops as either family food or for other users (Gaba and Bretagnolle, 2019), and the primary source of livelihood and income for farmers. In *Mexico highlands* all management types contribute to food security. Still, if harvest continues to be valued only through yield, the role of these small-scale systems in food security at local and regional levels could not be recognized. The operationalization of NCPs makes it possible to distinguish between the contribution to food self-sufficiency and food for markets. Within the regulation contributions, using stubble in all management types is critical for soil conservation in *Mexico highlands*. Especially considering that it is the only regulation contribution represented in management type one, where stubble is an effective way to compensate for the potential adverse effects of fertilizers and mechanical tillage (Lal, 2016). Rodríguez-Bustos et al. (2022b) point out that using manure to keep the soil covered reduces erosion and increases soil fertility.

Agricultural values refer to the specific relations of human nature constructed among broader values held by diverse stakeholders to produce better social-ecological outcomes in land systems (Ellis et al., 2019; Bruley et al., 2021). Each type of management in *Mexico highlands* reflects the unique value of agriculture for farmers (Díaz et al., 2018). The native seed, use of stubble, and residues to feed livestock are practices associated with conserving maize genetic resources, soil protection, supply of organic matter to the soil, and the design of resilient agriculture. Bellon et al. (2021) note that using native maize seed is the only strategy contributing to the local and regional food supply. In this research, we consider that native and hybrid seeds contribute to food security; native seeds contribute locally, and hybrid seeds at the regional scale. However, only the native seed gives continuity to what Bellon et al. (2021) called *additional incentives* related to maize, summarized as maintenance of genetic evolution, self-sufficiency, and alternative trade networks.

The coherence of agricultural management refers to agroecosystems with a particular farming system displaying individual (each farmer) but shared (farmers with similar management) goals. For example, in *Mexico highlands* each farmer selects the management practices applied in their plots. Even so, the purpose of attaining food self-sufficiency or selling to earn an income is shared with other farmers. For this reason, the NCPs identified from a management type could be integrated into the design of incentives according to the objective of management, the motivation of farmers, and the conservation of specific contributions. The contributions associated with cultural practices should not be deemed "additional" to the other benefits of agriculture, mainly because of the challenge of assigning a monetary or substitute value to the relationship of people with their environment (Swinton et al., 2007; Hanaček and Rodríguez-Labajos, 2018). In *Mexico highlands* agroecosystems that include traditional knowledge, like types one and two, are essential to understanding people's cultural identity and environmental sustainability (Hanaček and Rodríguez-Labajos, 2018). In these types of management, unlike type 3, we could identify that agriculture is their principal occupation, they have autonomous decisions about agricultural management, and their activities are subsistence-oriented. These are characteristics that, according to Wolf (1955), are common expressions of cultural values among peasants. Additionally, we agree with the vision of Rendón-Sandoval et al., 2021 by highlighting that traditional knowledge is expressed through the co-production of knowledge between the people who control and manage their resources because they represent a closer relationship with nature, compared to those who assume their autonomy from the market (Ploeg, 2010). Based on the present study results, integrating the typology with the NPC framework is an appropriate way to evaluate agricultural sustainability. It would reduce the focus on incentives in implementing a general management approach or disregarding the conservation of contributions and services. However, it is necessary to broaden the study of these aspects through an ethnographic vision, which lays the theoretical foundations and deepens aspects of traditional knowledge.

4.3. Land management sustainability in agroecosystems with cultural and natural value

Studies that quantify and integrate NPCs into agricultural ecosystems are vital for identifying benefits and trade-offs and making decisions involving these dualities. The response of governments to the 2030 Agenda to transition to sustainable agriculture has focused only on adjusting their policies to improve agricultural performance, such as promoting payment-based incentives to reduce agricultural expansion, funding for intensification, and incentives to implement environmentally friendly practices (Santos et al., 2021; Yazdanpanah et al., 2021). *MasAgro* was a technology transfer-based program, and the evidence indicates that it included intensification and environmentally friendly practices. However, there is evidence of the program's potential effect on farmers' decisions because the *bitácora única* characterizes the technologies the farmer intends to implement in the short term (Rodríguez-Bustos et al. in review). The sustainable transition of maize agroecosystems in Mexico requires understanding the adoption of specific management practices by farmers and the values assigned to different NPCs in all maize agricultural systems, from the milpa to monocrops. Before implementing actions affecting the natural and cultural value of small-scale maize agroecosystems, authorities should consider this. Some examples cannot be replicated, such as the political program named "*Kilo por Kilo*" in Mexico (1995–2000), which consisted of exchanging native for hybrid seeds to increase yield (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2020). One of the adverse effects of the program was the cross-breeding between native and hybrid seeds that led to the permanent modification of maize varieties in the southeast region [Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), 2020].

Bellon et al. (2005) point out that policy programs based on technology transfer play a central role in farmers' decision-making, mainly because they address limited access to improved seeds and synthetic fertilizers. In *Mexico highlands* the "*Fertilizantes para el Bienestar*" (Fertilizer for Welfare) program delivers up to 600 kg of synthetic fertilizers to small-scale maize farmers [Secretaría de Agricultura y Desarrollo Rural (SADER), (n.d.)] because the Mexican government prioritizes programs to improve access to fertilizers and hybrid seeds (Dionne and Horowitz, 2016). Continuing this type of incentive does not visualize the cultural appropriation of maize for farmers seeking management alternatives based on environmental protection practices (Dyer and Taylor, 2008; Hernández et al., 2022). We recognize that there is a counterpart from the government through the "Ley Federal para el fomento y protección del maíz nativo" and "Eliminación de Glifosato." However, at the time of this investigation, no farmers declare to be part of these initiatives. In the future, it will be necessary to evaluate the effect of these policies on agricultural management. These effects should be recognized in all agroecosystems because the effects will not be the same in polyculture and conservation systems, such as the milpa. Compared to small and large-scale monocultures, where the use of fertilizers is a common practice.

5. Conclusions

Based on FAMD and NbClust, the operationalization verifies that in *Mexico highlands,* the NCPs is regulated by the type of agricultural management. The factor analysis of mixed data showed that categorical variables such as seed type and tillage contribute to a greater extent to the definition of a management type than numerical variables such as yield or amount of fertilizer to separate groups and identify practices or objectives shared among farmers or farmer groups.

Identifying contributions associated with management practices is key to communicating the importance of the cultural value of agricultural landscapes. *Mexico highlands* is a region characterized by small-scale agriculture where the main contribution of nature, in addition to food production, is the cultural value of the conservation of native maize, the permanence of agricultural practices such as manual tillage and seed exchange, and the contribution of native maize to food self-sufficiency in the region. These cultural elements need to be recognized in the current political programs. The identified contributions can be included in agricultural sustainability assessments and used to consolidate a new strategy for communicating the cultural value of agriculture to decision-makers.

The evidence from the *MasAgro* program points out that achieving sustainable development goals requires avoiding policy programs based on yield evaluation success and proposing incentives for groups of farmers with common objectives or motivations. This information and political action can consolidate new planning tools and establish more effective strategies for communicating agriculture's natural and cultural values to decision-makers. The agricultural history of Mexico has been dominated by social movements and global economic impositions that have led it to operate based on economic incentives, which has yet to be entirely successful. Transitioning toward sustainable agriculture means including agroecosystems' natural and cultural value in financial incentives to conserve them.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

LR-B, LG, and MB participated in the project's design and coordinated the study. LR-B, LG, and NP-R participated in the design of the fieldwork. MB, IR, and LR-B participated in the design of methodology and data analyses. LR-B wrote the manuscript. LG, NP-R, MB, and IR reviewed the manuscript. NP-R included relevant information because of expertise in the region of study. All authors contributed to the article and approved the submitted version.

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Conflict of interest

NP-R was employed by CIMMYT.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1009447/full#supplementary-material

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