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SLOW-FORMING TERRACES IN A MILPA SYSTEM INTERCROPPED WITH FRUIT TREES IN THE NORTHWEST OF THE STATE OF MEXICO: BIOPHYSICAL AND SOCIOCULTURAL FACTORS

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ABSTRACT

In the State of Mexico, 24 % of the soil suffers from severe water erosion. The Intercropped Milpa with Fruit Trees (MIAF) system creates Slow-Forming Terraces (SFT) through the row of fruit trees and the runoff filter. Sociocultural and biophysical factors have been identified in soil conservation that determine the effectiveness of technologies applied by farmers. The objective of this research was to analyze the biophysical and sociocultural factors that influence FPT in the MIAF system in the northwestern State of Mexico. FPT was analyzed through two topographic surveys of six MIAF plots on hillsides. To identify sociocultural and biophysical factors in FPT, six semi-structured interviews were conducted with farming families, and erodibility, erosivity, topography, and vegetation cover indices were obtained. To identify related factors, the data were analyzed using Spearman's rank correlation coefficient ($p \leq 0.05$). A predictive model was generated using multiple linear regression for the statistically significant factors. The 21 identified sociocultural factors were subjected to cluster analysis to observe their grouping. Three biophysical and eight sociocultural factors associated with FPT were identified in the MIAF. The factors of erosivity, erodibility, topography, income, livestock farming, agricultural education, and agriculture as the main source of income predict the SFT (R^2 = 0.83). Plots with soil fertility were distinguished from those without by the factors of income, livestock farming, agricultural education, and agriculture as the main source of income. The consideration of biophysical and sociocultural factors is crucial for the successful implementation of soil conservation strategies in agricultural regions.

Keywords: Runoff filter, socioeconomic factors, Mazahua area, peasant agriculture, living wall barrier.

INTRODUCTION

In Mexico, water erosion affects 76 % of the national territory, with mild (37.06 %) and moderate (26.37 %) erosion predominating (Bolaños-González *et al*., 2016). In the northwestern region of the State of Mexico, 24 % of the soil presents severe erosion problems (INEGI, 2023). The Intercropped Milpa with Fruit Trees (MIAF) system addresses this problem through the gradual formation of living wall terraces (Cadena-Iñiguez *et al*., 2018). These terraces retain soil, store moisture, and improve working conditions without the cost of terrace construction, since they form over time (Kraemer *et al*., 2019).

The variability in the Slow-Forming Terraces (SFT) in the MIAF of the northwestern State of Mexico raises questions about the influence of sociocultural and biophysical factors. Although previous studies indicate that both types of factors influence MIAF (Turrent-Fernández *et al*., 1995; Camas-Gómez *et al*., 2012; Pillado-Albarrán *et al*., 2021), their combined analysis has not been addressed. Furthermore, their results cannot be generalized, as they depend on location and social context (Lapar and Pandey, 1999). Understanding which factors influence the slow formation of living wall terraces in this region is necessary for proposing management improvements that are appropriate to local conditions and moving toward more effective soil conservation.

Biophysical and sociocultural factors have both direct and indirect effects on the SFT. Specifically, biophysical factors influence sediment production (Yu *et al*., 2021), while sociocultural factors shape producers' decisions regarding the adoption of conservation technologies (Barrantes-Aguilar *et al*., 2024). Sklenicka *et al.* (2015) report that tenant farmers implement fewer conservation practices than landowners. Similarly, Sklenicka *et al*. (2019) found greater soil loss in plots with older producers who lack post-secondary education and rent their land.

Martínez-Castro *et al*. (2020) indicated that experience, education, economic resources, and plot size are positively associated with the adoption of conservation technologies. Likewise, Siyum *et al*. (2022) showed that the number of livestock and access to extension services influence the likelihood of adopting the technology under study. Regarding biophysical factors, studies report that the original slope (Turrent-Fernández *et al*., 1995; Camas-Gómez *et al*., 2012), erodibility, erosivity (Camas-Gómez *et al*., 2012; Liu *et al*., 2013), and vegetation cover (Bolaños-González *et al*., 2016) affect sediment production and retention.

Based on the biophysical and sociocultural characteristics documented by CONABIO (2023) and INEGI (2023) for the northwest region of the State of Mexico, as well as previous research on the MIAF (Turrent-Fernández *et al*., 1995; Camas-Gómez *et al*., 2012) and studies that incorporate sociocultural aspects (Sklenicka *et al*., 2019; Barrantes-Aguilar *et al*., 2024), several factors differentiate the SFT in living wall terraces within the MIAF system. These factors include poverty, migration, livestock practices, agricultural education, stubble management and pruning, erodibility, topography, and erosivity. The objective of this study was to analyze the biophysical and sociocultural factors that influence the SFT in MIAF plots of Mazahua peasant families in the State of Mexico to allow the development of collaborative strategies with the producers that focus on efficiency, sustainability, and adaptation to the biophysical and social context of the region.

MATERIALS AND METHODS

Study site

In the northwest of the State of Mexico, six hillside plots were established using the MIAF system (Figure 1). The first was established in 2018 in San Juan Coajomulco, Jocotitlán, with the producer Horacio Santiago-Mejía (SJC-HSM) (19° 44′ 19′′ N, 99° 57′ 18.7′′ W, altitude of 2650 m, precipitation of 825 mm, on Luvisol soil). Three plots were established in 2019 in Jaltepec, San José del Rincón, with María del Carmen Mateo-Salamanca (J-MCMS) (19° 35′ 37.3′′ N, 100° 5′ 51.3′′ W, altitude of 2718 m and precipitation of 811 mm), Francisco Vilchis-Maya (J-FVM) (19° 35′ 35.2′′ N, 100° 5′ 55.4′′ W, altitude of 2720 m and precipitation of 811 mm), and María del Carmen Marín-González (J-MCMG) (19° 36′ 24.8′′ N, 100° 6′ 23.6′′ W, altitude of 2713 m and precipitation of 840 mm). In 2020, another plot was established in Jaltepec, with Gloria Cárdenas-Morales (J-GCM) (19° 36′ 36.5′′ N, 100° 6′ 9.9′′ W, altitude of 2746 m and precipitation of 820 mm). The four plots in Jaltepec have Andosol soil. The last plot was established in 2020 in San Pablo Tlalchichilpa, San Felipe del Progreso, with Manuel Téllez-Hernández (SPT-MTH) (19° 42′ 58.98′′ N, 99° 59′ 6.19′′ W, altitude of 2669 m and precipitation of 831 mm, on Andosol soil).

Soil analyses indicate low levels of organic matter, with an average of 0.68 % in the surface layer (0–30 cm), and loam texture in all sites (Table 1). The six farming families who own these plots are members of the MIAF learning community and receive monthly training on technology. As part of the system, all plots are cultivated in strips of milpa with maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), squash (*Cucurbita* spp.), tomatoes (*Solanum lycopersicum* L.), marigold (*Tagetes erecta* L.), and faba beans (*Vicia faba* L.), interspersed with strips of fruit trees such as peach (*Prunus persica* (L.) Batsch), apple (*Malus domestica* Borkh.), tejocote (*Crataegus mexicana* Moc. and Sessé ex DC.), plum (*Prunus domestica* L.), pear (*Pyrus communis* L.), and walnut (*Juglans regia* L.).

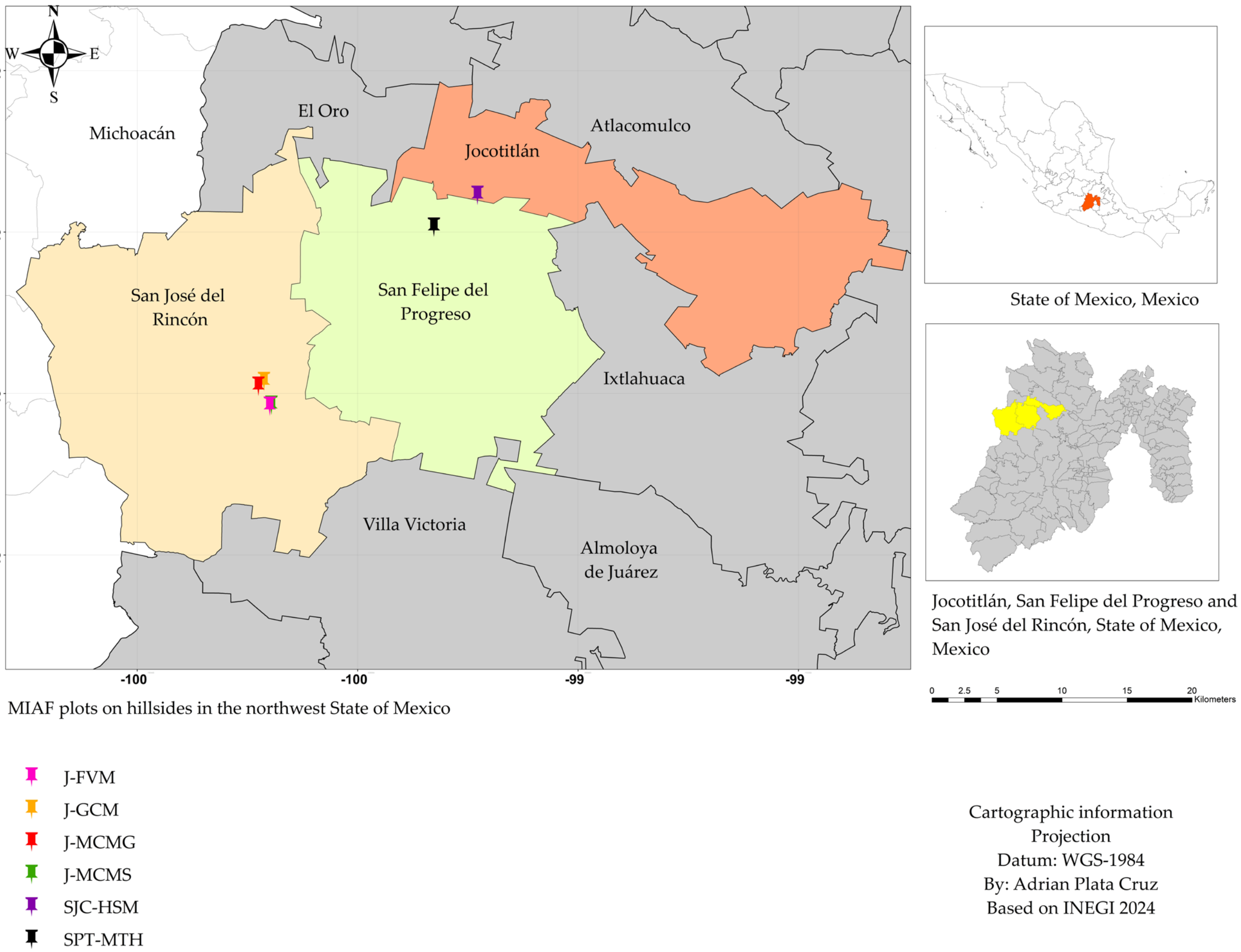

Figure 1. Location of the six Milpa Intercropped with Fruit Trees (MIAF) plots established on hillsides in three municipalities in the northwest of the State of Mexico, Mexico.

Table 1. Texture and organic matter (OM) of six plots with Intercropped Milpa with Fruit Trees (MIAF) in three municipalities of the northwest area of the State of Mexico, Mexico.

Plot	Sand (%)	Lime (%)	Clay (%)	OM (%)	Texture
SJC-HSM	41.55	43.83	14.61	0.59	Frank crumb
SPT-MTH	35.38	51.26	13.24	0.55	Lime frank
J-MCMS	33.19	36.01	30.79	1.05	Lime frank
J-GCM	30.13	57.31	12.55	0.91	Frank crumb
J-MCMG	35.01	49.85	15.12	0.49	Clayey loam
J-FVM	44.99	40.15	14.85	0.54	Frank crumb

SJC-HSM: San Juan Coajomulco, with Horacio Santiago-Mejía; SPT-MTH: San Pablo Tlalchichilpa, with Manuel Téllez-García; J-MCMS: Jaltepec, with María del Carmen Mateo-Salamanca; J-GCM: Jaltepec, with Gloria Cárdenas-Morales; J-MCMG: Jaltepec, with María del Carmen Marín-González; J-FVM: Jaltepec, with Francisco Vilchis-Maya.

Experiment management

Two types of modules were established: for plots with lower slopes (14.4 m) (SPT-MTH) and slopes greater than 10.6 m at 20 % (SJC-HSM, SPT-MTH, J-GCM, J-MCMS, and J-MCMG). Although the number of modules varied according to the size of the plot, only the first three were taken into account for this study, starting upstream. Each plot was managed in accordance with the technical recommendations (Cortés *et al*., 2005) provided during the MIAF learning community training sessions and in line with the criteria of each farming family.

Variables evaluated

Slow-forming terraces (SFT)

To evaluate the SFT, the following variables were calculated: 1) the original slope, 2) soil retention and loss in the MIAF modules for the years 2023 and 2024, and 3) changes in the slope of the terraces in the years 2023 and 2024. To determine the original slope, a topographic survey was conducted using a total station (Kolida KTS-442R6LC) that took readings every meter on the sides of the MIAF module where the system had not been altered by technology (Turrent-Fernández *et al*., 1995). Subsequently, the coordinates and profile of the original slope were projected using AutoCAD (Autodesk, Mill Valley, CA, USA) and CivilCAD 2021 software (CivilCAD, Tijuana, Mexico).

The estimation of soil retention and loss in the donor and recipient areas of the MIAF modules was carried out using two topographic surveys, the first in March 2023 and the second in March 2024. A total station (Kolida KTS-442R6LC) was used for this purpose. Readings were taken every meter or at each notable change in the topography of the terrain in five specific areas of the MIAF module (Figure 2).

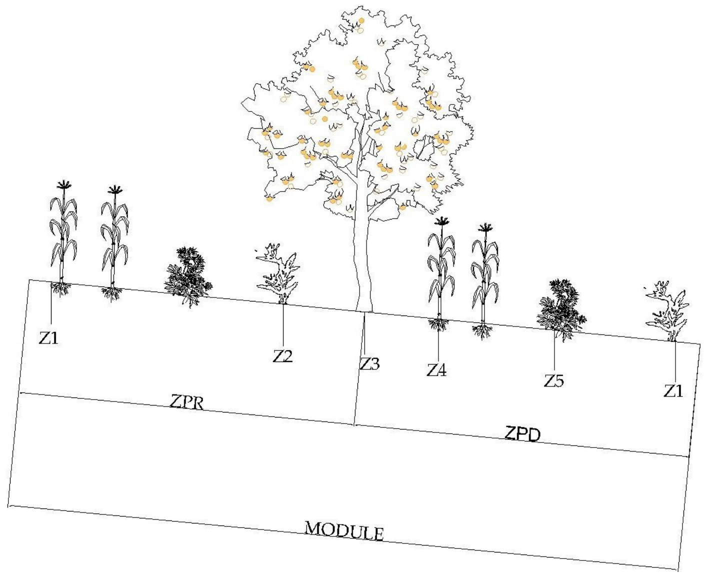

Figure 2. Cross-section of the Intercropped Milpa with Fruit Trees (MIAF) module, showing the points where topographic surveys were conducted on the six plots. Z1: start of the MIAF module; Z2: sediment receiving area; Z3: row of fruit trees; Z4: donor area; Z5: transport area. ZPR: potential sediment receiving area; ZPD: potential sediment donor area.

Using the readings from the topographic surveys, 1) the profiles of the original slope and the topography for 2023 and 2024 were projected; 2) the areas of soil loss and gain for both years were calculated; and 3) soil retention and loss (in Mg ha^{-1}) were obtained using the following formulas:

For modules with a slope >20 %,

$$ST = \frac{A * D * (5000/5.3)}{1000}$$

where ST is total soil (in Mg ha^{-1}), A is the area given by the profile comparison (in m^2), D is the soil bulk density (in kg m^{-3}), 5000 is the potential area of sediment loss or retention (in m^2) in one hectare of MIAF according to Turrent-Fernández *et al*. (1995), 5.3 is the length of the potential area of sediment loss or gain (in m) in a MIAF module with a slope >20 % (Turrent-Fernández *et al*., 1995), and 1000 is the conversion factor from kg to Mg.

For modules with a slope <20 %,

$$ST = \frac{A * D * (5000/7.2)}{1000}$$

where ST is total soil (in Mg ha^{-1}), A is the area given by the comparison of profiles (in m^2), D is the soil bulk density (in kg m^{-3}), 5000 is the potential area of sediment loss or gain (in m^2) in one hectare MIAF (Turrent-Fernández *et al*., 1995), 7.2 is the length of the potential area of sediment loss or gain (in m) in a MIAF module with a slope <20 % (Turrent-Fernández *et al*., 1995), and 1000 is the conversion factor from kg to Mg.
The slope changes in 2023 and 2024 were analyzed using profiles obtained from the areas where milpa is cultivated, without considering the barrier or the row of fruit trees, with the help of AutoCAD software.

Biophysical characterization of the plots

Erodibility

Soil samples were taken from the 0–30 cm layer for each of the six MIAF plots. These samples were analyzed following the method described by van Reeuwijk (1999). Data on texture, density, and organic matter content were obtained. Soil susceptibility to erosion was assessed using the K factor from the universal soil loss equation proposed by Wischmeier and Smith (1978), using the following formula:

$$K = 0.1317 * f_{csand} * f_{cl-si} * f_{organic} * f_{hisand}$$

where f_{csand} is the factor related to sand content, $f_{cl\text{-}si}$ is the factor related to silt and clay content, $f_{organic}$ is the factor related to organic carbon content, f_{hisand} is the parameter related to sand content, and 0.1317 is the conversion factor.

Rain erosivity

A rain gauge was installed in each of the six plots, and precipitation was recorded. To evaluate this parameter, the *R* factor of the Universal Soil Loss Equation (USLE) was selected according to Wischmeier and Smith (1978), using the method of Cortés-Torres *et al.* (1992), who divided the country into 14 zones and assigned a regression equation to each. The northwestern zone of the State of Mexico corresponds to zone V, which is defined by the following formula:

$$R = 3.4880P + 0.00088P^2$$

where *P* is the average annual precipitation, which in this case corresponds to the precipitation recorded in each rain gauge in a year.

Topography

The slope grade and length were evaluated using the USLE dimensionless slope-length (*LS*) factor for uniform slopes, according to Wischmeier and Smith (1978). Its calculation was performed using the topographic survey processed in AutoCAD and CivilCAD 2021. The *LS* topographic factor was obtained with the following formula:

$$LS = \left(\frac{X}{22.13}\right)^m (65.41 + 4.56s + 0.065s^2)$$

where *L* is the slope length factor, *S* is the slope inclination factor, *X* is the slope length (in m), *m* is the constant that depends on the slope inclination, and *s* is the inclination (in percent).

Plant cover

Given the difficulty of continuously monitoring the six plots, a structured questionnaire was used to record the species cultivated. Each plot could include one or more crops to which a vegetation cover index was assigned (Lianes *et al*., 2009). The values for the crops present in each plot were averaged to obtain a representative vegetation cover index per plot.

Sociocultural characterization of peasant families

Using a semi-structured questionnaire based on the guidelines proposed by Geilfus (2005), the information on various sociocultural variables was gathered among peasant families. The questionnaire addressed topics such as migration, economic income, livestock, agricultural education, primary and secondary economic activities, health, cultural practices related to the milpa, beliefs, ethnicity, time spent with technology, challenges in attending the MIAF community, scheduling of milpa-related activities, types of machinery or animals utilized, available labor, the influence of various stakeholders, crop management practices, ownership status (owner or tenant), perceptions of erosion, pruning management, and stubble management.

Statistical analysis

A descriptive analysis was performed to evaluate the data related to the gradual formation of terraces. Sediment retention levels and the 25 sociocultural and biophysical soil factors were analyzed using Spearman's bivariate correlation in InfoStat 2020. A multiple linear regression model was constructed using the statistically significant variables in Past 2022. Finally, a cluster analysis was carried out with the 21 sociocultural factors using Ward's method and squared Euclidean distance, using InfoStat 2020.

RESULTS AND DISCUSSION

Gradual formation of terraces

Slow-forming terraces (SFT) varied among the six plots evaluated. In order of efficiency, SJC-HSM, J-MCMS, and SPT-ETH exhibited FPT due to soil loss and gain in the donor and recipient areas, respectively, and to the reduction of their original slopes. In the 2023 and 2024 topographic surveys, the three plots showed a similar pattern: in the donor area of the first module, soil loss was greater and gradually decreased toward the third module; in the recipient areas, the greatest retention was recorded in the second module. This indicates that the system is not closed and that the soil coming from the upper part (module 1) is mainly retained in the middle part (module 2) (Table 2).

In SJC-HSM, the amount of soil gained or lost decreased over time, coinciding with slope reductions of 50.14 and 33.39 % compared to the original slope and with stabilization. In contrast, in SPT-MTG and J-MCMS, the amounts of soil gained or lost were not yet stabilized, which is reflected in smaller slope reductions (20 and 14.42 %, respectively) (Table 3).

In the plots without SFT (in descending order, J-MCMG and J-FVM), soil movement was indiscriminate between receiving and donor zones. Transport was observed only from the first module to the third (Table 2), exhibiting a pattern of gain and loss over time. Although the slope temporarily decreased in both plots, the terraces returned to their original slope as the gained soil was lost; therefore, there was no stabilization of the slope changes (Table 3). In plot J-GCM, the gradual formation of terraces was partial, as it appeared in the first two modules but not in the third. Furthermore, the

Table 2. Slow-forming terraces in six plots with Intercropped Milpa with Fruit Trees (MIAF) in three municipalities of the northwest area of the State of Mexico.

Plot	Year	Module 1 (PAL)		Module 2 (PML)		Module 3 (PBL)	
		Recipient ($Mg\ ha^{-1}$)	Donor ($Mg\ ha^{-1}$)	Recipient ($Mg\ ha^{-1}$)	Donor ($Mg\ ha^{-1}$)	Recipient ($Mg\ ha^{-1}$)	Donor ($Mg\ ha^{-1}$)
SJC-HSM	2023	663.57	-521.62	851.92	-173.44	623.37	-39.71
	2024	130.06	-129.64	203.29	-47.37	150.52	-9.37
SPT-MTH	2023	196.99	-117.64	276.28	-51.27	85.98	-51.42
	2024	37.73	-41.27	124.67	-28.51	37.26	-14.86
J-MCMS	2023	290.79	-224.91	404.93	-157.27	227.99	-116.08
	2024	103.48	-69.74	139.73	-52.82	68.62	-34.26
J-GCM	2023	139.37	-82.85	143.41	-68.33	110.66	65.41
	2024	100.69	-64.91	122.57	-55.97	-79.21	-64.74
J-MCMG	2023	665.50	379.52	1274.31	46.70	-189.86	-438.81
	2024	-177.74	-417.84	-593.98	-298.60	660.98	633.88
J-FVM	2023	-216.39	-482.15	-253.40	-141.82	852.48	920.49
	2024	377.97	125.96	-213.16	-483.35	-992.97	-1020.12

SJC-HSM: San Juan Coajomulco, with Horacio Santiago-Mejía; SPT-MTH: San Pablo Tlalchichilpa, with Manuel Téllez-García; J-MCMS: Jaltepec, with María del Carmen Mateo-Salamanca; J-GCM: Jaltepec, with Gloria Cárdenas-Morales; J-MCMG: Jaltepec, with María del Carmen Marín-González; J-FVM: Jaltepec, with Francisco Vilchis-Maya; PAL: upper part of the slope; PML: middle part of the slope; PBL: lower part of the slope.

soil entering through the first module was not retained in any of them (Table 2), and the change in slope in the cultivable area was minimal between the first and second modules and nonexistent between the second and third (Table 3).

Spearman's bivariate correlation analyses between the total levels of retained soil and the 25 sociocultural and biophysical factors showed significant correlations ($p \leq 0.05$) only for erodibility (0.56), erosivity (0.61), topography (0.64), economic income (0.65), livestock (-0.61), agricultural education (0.51), agriculture as the main source of income (0.56), years with MIAF (0.61), external labor (0.56), stubble use (0.58), and pruning residues in the runoff filter (0.58). With these factors, the multivariate linear regression analysis showed that erosivity, erodibility, topography, economic income, livestock, agricultural education, and agriculture as the main source of income generate a prediction equation for soil retention levels ($R^2 = 0.83$), with a greater contribution from sociocultural factors compared to biophysical ones:

$$SR = 1599.5 - 0.2276\,ES + 20035\,ED + 184.42\,T + 300.99\,IE + 918.15\,G - 529.04\,EA + 1474.1\,AP$$

Table 3. Percentage change in slope on the terrace in the cultivable areas between strips of fruit trees in plots with Intercropped Milpa with Fruit Trees (MIAF) in three municipalities of the northwest of the State of Mexico, Mexico.

		Module 1 Module 2	Module 2 Module 3
Plot	Year	Donor Recipient (%)	Donor Recipient (%)
	PO	10.51	10.51
SJC-HSM	2023	5.24	7.00
	2024	5.24	7.00
	PO	8.75	8.75
SPT-MTH	2023	7.00	7.00
	2024	7.00	7.00
	PO	12.28	12.28
J-MCMS	2023	10.51	10.51
	2024	10.51	10.51
	PO	12.28	12.28
J-GCM	2023	10.51	12.28
	2024	10.51	12.28
	PO	21.26	21.26
J-MCMG	2023	17.63	21.26
	2024	21.26	19.39
	PO	10.51	10.51
J-FVM	2023	10.51	7.00
	2024	10.51	10.51

SJC-HSM: San Juan Coajomulco, with Horacio Santiago-Mejía; SPT-MTH: San Pablo Tlalchichilpa, with Manuel Téllez-García; J-MCMS: Jaltepec, with María del Carmen Mateo-Salamanca; J-GCM: Jaltepec, with Gloria Cárdenas-Morales; J-MCMG: Jaltepec, with María del Carmen Marín-González; J-FVM: Jaltepec, with Francisco Vilchis-Maya; PO: Original pending.

where *SR* is the retained soil, 1599.5 is the constant, *ES* represents erosivity, *ED* erodibility, *T* topography, *IE* economic income, *G* livestock, *EA* agricultural education, and *AP* agriculture as the main source of income.

In plots where slow terraces formation was not observed, the biophysical factors did not show a consistent relationship. For example, in J-FVM and J-MCMG, current erosion differs considerably (19.13 and 62.56 Mg ha^{-1} $year^{-1}$, respectively), but this was not reflected in differences in the SFT (Table 4). Similarly, in the adjacent plots J-MCM and J-FVM, which share biophysical factors and similar upstream conditions, one presented SFT and the other did not (Figure 3).

Table 4. Biophysical factors and potential erosion in six plots with Intercropped Milpa with Fruit Trees (MIAF) in three municipalities in the northwest area of the State of Mexico.

Plot	Erodibility (dimensionless)	Erosivity (MJ ha^{-1} mm h^{-1})	Topography* (dimensionless)	Vegetation cover index	Adoption of conservation practices	Current erosion (Mg ha^{-1} year^{-1})
SJC-HSM	0.028	2278.65	2.135	0.407	0.60	32.69
SPT-MTH	0.022	2290.00	1.174	0.407	0.60	14.19
J-MCMS	0.025	2250.00	2.369	0.407	0.60	31.98
J-GCM	0.022	2268.30	1.882	0.407	0.60	22.54
J-MCMG	0.024	2310.30	3.526	0.407	0.80	62.56
J-FVM	0.026	2250.00	1.363	0.407	0.60	19.13

*Topography: topographic length-slope (LS) factor of the Universal Soil Loss Equation (USLE). SJC-HSM: San Juan Coajomulco, with Horacio Santiago-Mejía; SPT-MTH: San Pablo Tlalchichilpa, with Manuel Téllez-García; J-MCMS: Jaltepec, with María del Carmen Mateo-Salamanca; J-GCM: Jaltepec, with Gloria Cárdenas-Morales; J-MCMG: Jaltepec, with María del Carmen Marín-González; J-FVM: Jaltepec, with Francisco Vilchis-Maya.

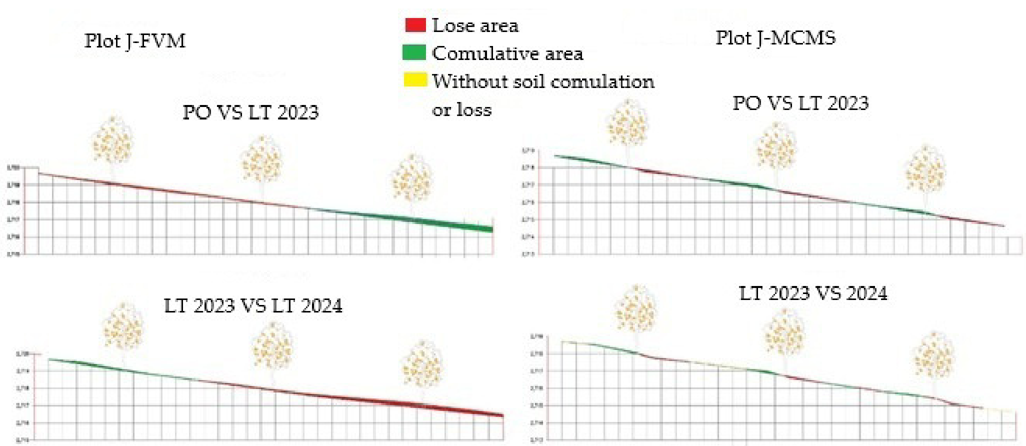

Figure 3. Profile contrast of two adjacent plots with Intercropped Milpa with Fruit Trees (MIAF) in the third (2023) and fourth year (2024) after their installation.

Sociocultural factors

Similarly, cluster analysis applied to sociocultural factors showed that plots with terraced fields (SFT) clustered together and were distinct from those with no or low terrace formation (Figure 4). Among the 21 sociocultural factors evaluated, it was the socioeconomic factors that differentiated production units exhibiting gradual terrace formation (SJC-HSM, SPT-ETH, and J-MCMS). Common factors included income, livestock, agricultural education, agriculture as the main source of income, years of implementation of MIAF, use of external labor, and management of runoff filters.

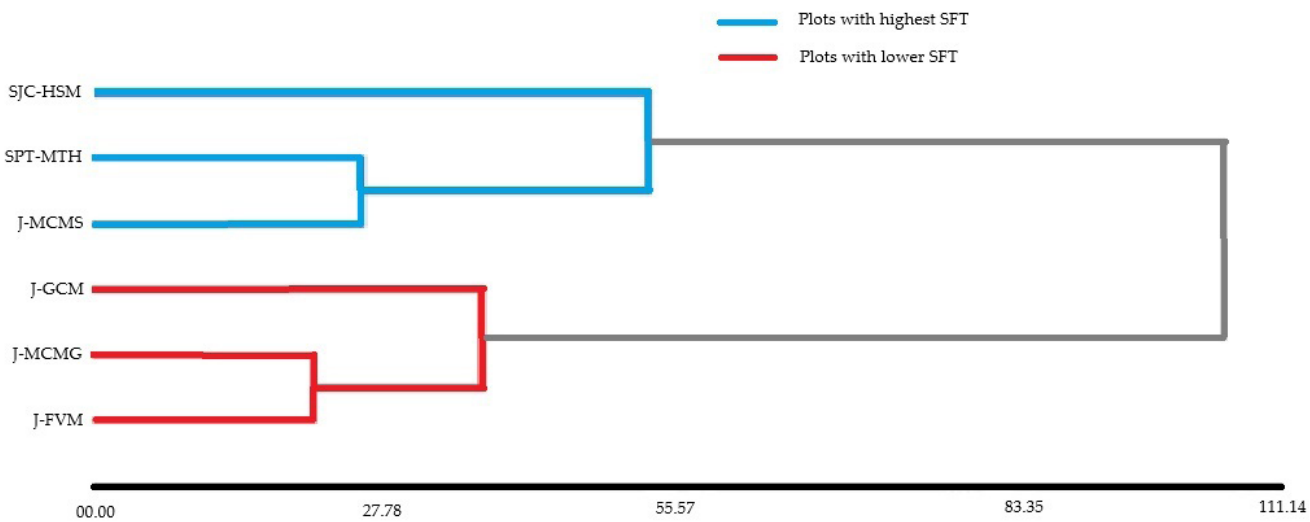

Figure 4. Grouping based on sociocultural factors of plots with Intercropped Milpa with Fruit Trees (MIAF) with and without Slow-Forming Terraces (SFT) in the northwest of the State of Mexico, Mexico.

The soil loss pattern in the donor areas of the plots with SFT coincided with that reported by Turrent-Fernández *et al*. (1998), where the greatest losses were concentrated in the upstream modules and decreased downstream. Sediment input into the system was documented, as soil loss was lower than the amount retained. In the SJC-HSM plot, which was managed according to the recommendations of the MIAF system, the practices included the placement of a runoff filter and the verification of soil turning downstream. Soil retention in this plot ranged from 542.45 to 756.7 m^3 ha^{-1} with 825 mm of annual precipitation.

In experimental plots with living wall terraces, where the filter and tillage were also controlled, the reported retention was 720 to 937 m^3 ha^{-1} with 1750 mm of precipitation (Turrent-Fernández *et al*., 1995). In these experimental contexts, the FPT is attributed to the interaction between biophysical and management factors, such as erosivity, slope, soil type, and tillage (Turrent-Fernández *et al*., 1995; Camas-Gómez *et al*., 2012; Liu *et al*., 2013). The gradual decrease and subsequent stabilization of the slope in the FPT occurred around the fourth year, a period similar to that observed in terraces with living walls of *Gliricidia sepium* (Jacq.) Kunth ex Walp., *Leucaena leucocephala* (Lam.) de Wit (Turrent-Fernández *et al*., 1995), and agroforestry systems with fruit trees (Do *et al*., 2023).

When plots are not experimental and management depends on farming families, socioeconomic factors explain the presence or absence of SFT. Agricultural education in at least one family member was common in plots with SFT, which favored appropriate practices such as the placement of the living wall. In this regard, Lal (2001) and Tesfahunegn *et al*. (2021) point out that agricultural education improves understanding of the soil ecosystem, strengthens attitudes toward conservation (Lalani *et al*., 2016), and develops practical skills (Cipriano *et al*., 2022). Furthermore, it is associated with higher incomes (Siyum *et al*., 2022) and greater investment capacity and decision-making power (Martínez-Castro *et al*., 2020; Regalado-López *et al*., 2020). Higher incomes provide access to tools that facilitate the management and adoption of conservation technologies (Martínez-Castro *et al*., 2020).

In plots where there was no SFT, families had lower incomes and less access to resources. In J-FVM, the runoff filter was not installed because the crop residue was used as fodder and the pruning waste as firewood. According to Siyum *et al*. (2022), the adoption of certain plant species in agroecosystems is limited by the need for animal fodder. In J-GCM, the lack of access to LP gas forced the use of pruning waste as fuel. Barrantes-Aguilar *et al*. (2024) indicate that, even with training in soil conservation, families prioritize basic needs over conservation. Morales and Parada (2005) and Cotler *et al*. (2020) maintain that poverty limits the proper management of agroecosystems and perpetuates soil degradation.

CONCLUSIONS

The slow-forming terraces in plots using the Intercropped Milpa with Fruit Trees technology, managed by Mazahua families in the State of Mexico, were influenced by the interaction of sociocultural and biophysical factors. Although erodibility, erosivity, topography, and vegetation cover showed different behaviors among plots, they were not the only factors that influenced terrace formation. Soil retention levels were predicted by erosivity, erodibility, topography, economic income, livestock, agricultural education, and agriculture as the main source of income.

The use of crop residue as fodder or fuel affected the establishment of the runoff filter, preventing the gradual formation of terraces. In the plots where gradual terrace formation did occur, soil losses and gains decreased over time, and the slope stabilized by the fourth year. In the plots without terrace formation, the donor and recipient zones were indistinguishable, and soil movement was temporary and indistinct. For the successful establishment of soil conservation technologies in peasant agroecosystems, it is important to consider biophysical and sociocultural factors, and the latter to a greater extent.

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