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RESEARCH ARTICLE

Organic carbon sequestration potential in alluvial agricultural terraces: A case study of a lama-bordo system in Oaxaca, Mexico

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ABSTRACT

Soil is the primary C reservoir in terrestrial ecosystems and provides a variety of ecosystem services. Therefore, quantifying soil organic C (SOC) storage is essential for conservation technologies that ensure the sustainability of this non-renewable resource. In this context, the objective of this study was to estimate the SOC content within a pre-Hispanic agricultural terrace system, known locally as lama-bordo, in the Mixteca Alta region of Oaxaca, Mexico, using soil sampling, remote sensing, and geographic information systems. Based on the organic matter content, the SOC was determined in each soil sample from the surface layer (0-30 cm). The total SOC content in the lama-bordo system (LBS) was estimated using the average depth of each section and a high-resolution digital elevation model. The results indicate that the LBS is capable of storing between 254.88 and 449.68 Mg ha^{-1} SOC, which can prevent the emission of C into the atmosphere through its conservation. These findings highlight the need for further research to generate more comprehensive knowledge of the functions of alluvial agricultural terraces.

Key words: Carbon storage, lama-bordo system, soil conservation, sustainable agroecosystems.

INTRODUCTION

The soil is the largest C reservoir in terrestrial ecosystems and plays a key role in stabilizing atmospheric CO_2 concentrations (Jackson et al., 2017; Georgiou et al., 2022; Ali et al., 2025). It is estimated that C stocks reach 677 Pg at 0.3 m, 993 Pg at 0.5 m, and 1505 Pg at 1 m depth (Lal, 2018); at the latter depth, mineral soils contain about 899 Pg (Georgiou et al., 2022). Climate and land-use change can alter the C cycle and create large terrestrial C sinks or sources, such as agricultural terraces, which are also considered important soil organic C (SOC) storage sites (Brown et al., 2021; Georgiou et al., 2022).

The SOC is important because it affects soil quality, functionality, and health, as it is part of organic matter (45%-60%) (Lal, 2016). Its sequestration can be enhanced through better management of forest and agricultural lands, which offer high potential for global CO_2 mitigation. However, if managed unsustainably, these practices can alter soil C stocks (Jackson et al., 2017). Although SOC is highly dynamic, its average residence time depends on the degree of physical, chemical, and biological protection within the soil (Lal, 2016).

Erosion is one of the main processes that leads to the loss of SOC (Lal, 2018), as it detaches a large amount of particles from the soil surface. In this regard, there is a close relationship between SOC loss and soil conservation strategies. Much of the SOC redeposited downslope is actively replaced when new vegetation grows on eroded surfaces in upland areas, causing the watershed system to function as a net sink of SOC (Ferguson et al., 2020).

Terraces, functioning as soil and water conservation structures, have played an important role in preserving soil and water (He et al., 2025), serving as a traditional engineering adaptation strategy for land use in mountainous areas (Liu and Zhou, 2017). In addition, they provide ecosystem services that contribute to mitigating aspects of climate change, including sediment and nutrient deposition, increased SOC stocks (Brown et al., 2021), erosion control, enhanced biomass production, and soil water recharge. Before the development of modern engineering, terrace systems, such as the lama-bordo system (LBS), were rarely constructed in a single phase; rather, they evolved gradually, with erosion playing a central role in sustaining these systems (Ferro-Vázquez et al., 2017).

The Mixteca Alta region is located in the Sierra Madre del Sur physiographic province, in the northwestern part of the state of Oaxaca, Mexico. Historically, this region has faced problems related to the degradation of natural resources, mainly soil erosion, caused by the interaction of geological, topographic, and human factors (Toledo-Medrano et al., 2018). This issue has been studied and documented by several authors (Palacio-Prieto et al., 2016; Santiago-Mejía et al., 2018; Pérez-Sánchez, 2019). According to INEGI (2014), 54% of the current erosion is water related. The original vegetation is limited to small areas of oak and pine forests at high altitudes (Palacio-Prieto et al., 2016). This situation posed a challenge for the Chocho-Mixteca communities, who had very limited land suitable for agriculture. In response, the inhabitants developed an agricultural terrace system known as lama-bordo.

The LBS is a series of pre-Hispanic agricultural terraces (Santiago-Mejía et al., 2018; Pérez-Sánchez, 2019) built along the natural channels of intermittent streams. These streams carry soil particles (Palacio-Prieto et al., 2016) from higher areas and nearby slopes, helping to reduce soil erosion and benefiting regional agriculture (Santiago-Mejía et al., 2025). Each terrace consists of a stone wall or compacted earth barrier that gradually traps sediments and nutrients, creating leveled surfaces suitable for food production. Some of these terraces are estimated to be at least 3400 yr old, as indicated by the study of Leigh et al. (2013). According to Shi et al. (2019), this type of terrace affects SOC dynamics through changes in land use, alterations in local topography and hydrological conditions, and the redistribution of soil particles. As a result, these systems form soils enriched in nutrients and SOC, demonstrating a sustainable and resilient agricultural practice over time.

Studies conducted in Spain at the national level determined that the average SOC content in the soil surface is 56.57 Mg ha^{-1}, and the total amount stored in the topsoil layer was 2.8 Pg C (Rodríguez-Martín et al., 2016). In the case of China, specifically for terraces, it was found that terrace construction increased SOC sequestration by an average of 32.4%. The age of the terraces is a key factor in the degree of SOC sequestration, since terraces that were 1 to 2 yr old showed an average decrease of 6.4%, probably due to the disturbance of soil aggregates during excavation and redistribution. In contrast, terraces older than 5 yr were more effective in SOC sequestration (Chen et al., 2020).

Several studies conducted to estimate SOC have used geostatistics, at different scales, as a tool. Patel et al. (2024) concluded that the inverse distance weighting (IDW) interpolation method was the most effective for predicting SOC at soil depths of 60-90 cm. Similarly, Van Huynh et al. (2022) compared three methods for SOC estimation (IDW, ordinary kriging, and random forest) and confirmed that the IDW method was the most accurate for small-scale mapping of this variable. Likewise, Tang et al. (2017) studied forest soils and estimated SOC using both kriging and IDW methods, concluding that both are suitable for analyzing the spatial distribution of SOC stocks. Zhang et al. (2020) analyzed SOC distribution in agro-pastoral soils at depths using ordinary kriging and IDW methods. Their results showed that the estimates were similar, but the IDW method produced a more detailed SOC map.

However, despite the widely recognized benefits of terraced systems for soil conservation, their potential for SOC storage remains largely unexplored. Therefore, based on the importance of SOC in climate change mitigation and sustainable agriculture, this study aims to estimate the SOC content within a LBS in the Mixteca Alta region of Oaxaca, employing soil sampling, remote sensing, and geographic information systems.

MATERIALS AND METHODS

Study area

The lama-bordo system (LBS) is located in a micro-watershed in Santiago Amatlán (17°51′00″-17°53′00″ N, 97°22′00″-97°25′00″ W), municipality of Asunción Nochixtlán, in the Mixteca Alta region of Oaxaca, Mexico. Based on the Köppen climate classification, modified by García (2004), the area has a BS1kw semi-arid temperate climate, with an annual mean temperature of 16.18 °C, and summer rainfall, and an average annual precipitation of 601.81 mm. The predominant soils are Luvisols (98.15%) and Vertisols (1.85%) (Figure 1).

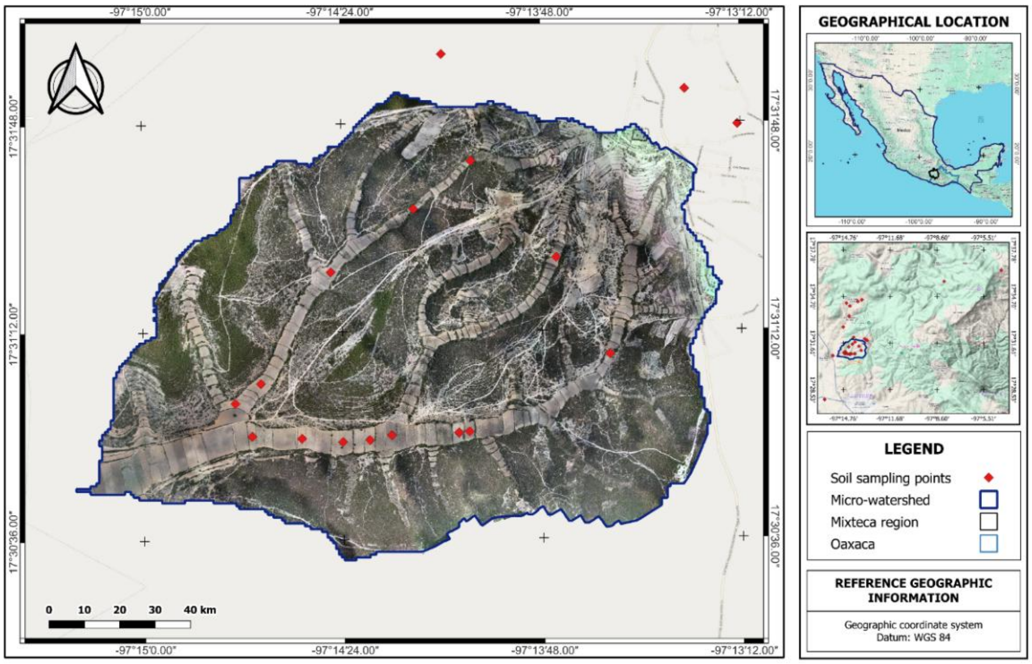

Figure 1. Location of the lama-bordo system and soil sampling points.

Methodology for estimating total soil organic C in the LBS

Figure 2 summarizes the methodology used during the research process to estimate the total soil organic C (SOC) of the LBS under study. The subsequent sections describe each stage in detail.

Soil sampling and analysis

A total of 27 soil samples were randomly collected, including 14 from within the LBS (samples 1-14) and 13 from adjacent areas (samples 15-27), each weighing approximately 1 kg and taken from the 0-30 cm soil layer. All samples were georeferenced. Subsequently, soil organic matter (OM) was determined following the Walkley and Black method (Walkley and Black, 1934). Bulk density (BD) was measured using one soil core per sampling site, collected in polyvinyl chloride (PVC) rings with a diameter of 7.62 cm and a length of 10 cm. The cores were oven-dried at 105 °C for 48 h and subsequently weighed to determine their mass.

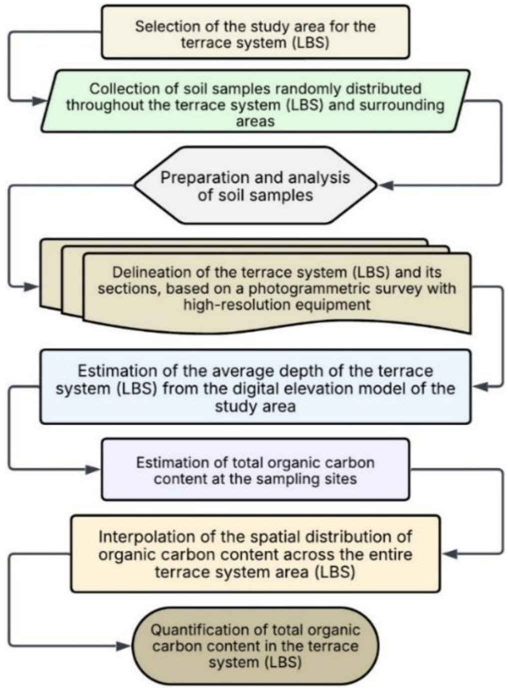

Figure 2. Methodology employed for estimating total soil organic C content in the lama-bordo system (LBS).

Photogrammetric survey

A total of 2520 images (with 80% longitudinal and 80% lateral overlap) were captured using a Phantom 4 Pro unmanned aerial vehicle (UAV) (DJI, Beijing, China). It was equipped with a digital camera with a 1″ CMOS sensor (fixed focal length of 8.8 mm, sensor size 11.407 × 8.556 mm). The images were processed using Pix4Dmapper Pro software version 3.1.22 (Pix4D, Prilly, Switzerland), to generate an orthomosaic and a digital elevation model (DEM) of the micro-watershed, with a spatial resolution of 0.2 m and a vertical accuracy of 0.046 m.

The DEM was hydrologically corrected following the method of Wang and Liu (2006). The orthomosaic enabled precise delineation of the LBS at the plot level using a geographic information system (GIS). This was then used to calculate the area of each section and the total LBS area (Figure 3).

Figure 3. Visualization of the lama-bordo terrace system.

Estimation of the mean depth of the LBS

The mean depth of each LBS section was determined using the DEM and Equation 1, providing a more accurate estimation of terrace SOC content:

$$\mathrm{DeS} = \left(\frac{\mathrm{E_M} - \mathrm{E_m}}{\mathrm{TN}}\right) \times 100 \qquad (1)$$

where DeS is the mean depth of each LBS section (cm), E_M is the maximum altitude (m), E_m is the minimum altitude (m), and TN is the total number of terraces in each LBS section.

Estimation of SOC at the sampling sites

Based on the determination of OM in each sample, SOC content was estimated using the Van Bemmelen conversion factor (1.724), which assumes that organic C (OC) constitutes 58% of OM. Subsequently, SOC content at the sampling points was estimated to a depth of 30 cm (SOC_{30}), providing point-specific concentrations and suitable for interpolation (Equation 2) (Łopatka et al., 2023):

$$\mathrm{SOC_{30}} = \mathrm{BD} \times \mathrm{Ssd} \times \mathrm{OC} \qquad (2)$$

where SOC_{30} is the soil organic C content at 30 cm (Mg ha^{-1}), BD is the soil bulk density (g cm^{-3}), Ssd is the soil sample depth (cm), and OC is the organic C (%).

Interpolation and estimation of SOC in the LBS

The SOC within the LBS was interpolated using the values and coordinates of the sampling points (Figure 1). Interpolation was performed using the inverse distance weighting (IDW) method in QGIS 3.28.0. (QGIS, Grüt, Switzerland). After obtaining the raster of SOC_{30} distribution and the estimated depth of each LBS section (DeS), Equation 3 was applied using the raster calculator:

$$\mathrm{SOC_T} = \frac{\mathrm{DeS} \times \mathrm{SOC_{30}}}{\mathrm{Ssd}} \qquad (3)$$

where SOC_T is SOC in the LBS (Mg ha^{-1}), DeS is the mean depth of each LBS section (cm), SOC_{30} is SOC content at 30 cm (Mg ha^{-1}), and Ssd is the soil sample depth (cm).

Reclassification of SOC interpolation

Finally, the obtained layers were reclassified into four class for SOC_{30} and six class for SOC_T (Table 1), and then converted into vector format to calculate the area of each category.

Table 1. Measured and estimated parameters for the soil samples. SOC_{30}: Soil organic C content at 30 cm; SOCT: soil organic C in the lama-bordo system.

Class	SOC_{30} (Mg ha^{-1})	Class	SOC_T (Mg ha^{-1})
1	15.22-20.00	1	111.10-300.00
2	20.00-30.00	2	300.00-500.00
3	30.00-40.00	3	500.00-700.00
4	40.00-53.83	4	700.00-900.00
		5	900.00-1100.00
		6	1100.00-1268.21

RESULTS AND DISCUSSION

Characteristics of the LBS

For centuries, agricultural terraces have allowed the conservation of soil and water, which are used for food production. One of the key ecosystem services provided by these structures is C sequestration (Socci et al., 2019), a process that has been relatively little studied (Martínez-Mena et al., 2019). Two types of terraces can be distinguished: Those located on hillslopes and those established along stream channels, such as the lama-bordo system (LBS).

The soil organic C (SOC) deposits of alluvial origin found in the LBS of the Mixteca Alta region make a substantial contribution to maintaining ecological balance. This is particularly relevant given the significant changes in SOC content, which directly affect atmospheric carbon dioxide concentrations and, consequently, contribute to global climate change (Adeniyi et al., 2024). Deposition and burial processes promote the formation of macroaggregates, thereby protecting organic C (OC) from microbial decomposition (Martínez-Mena et al., 2019).

The photogrammetric survey revealed that the micro-watershed where the LBS is located covers 595.90 ha, with altitudes ranging from 2084 to 2317 m and slopes between 0.0% and 398.83% (Figure 4).

The LBS consists of 385 agricultural terraces, organized into 22 sections, occupying 17.45% (104 ha) of the micro-watershed (Figure 5). These terraces are distributed at altitudes of 2085 to 2280 m, with slopes varying from 0.0% to 152.07%. It is important to note that the steepest slopes occur along the terrace walls, while the gentlest slopes are found on the cultivable surfaces.

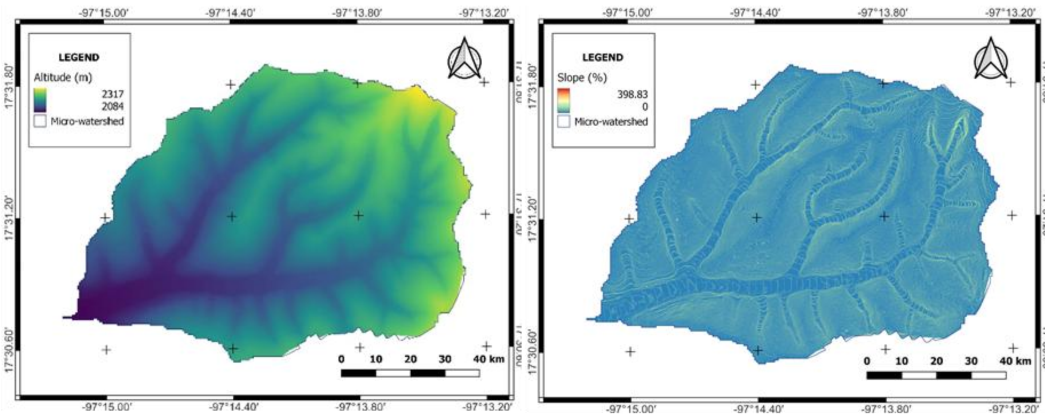

Figure 4. Spatial distribution of altitude (a) and slope (b) of the micro-watershed where the lama-bordo system is located.

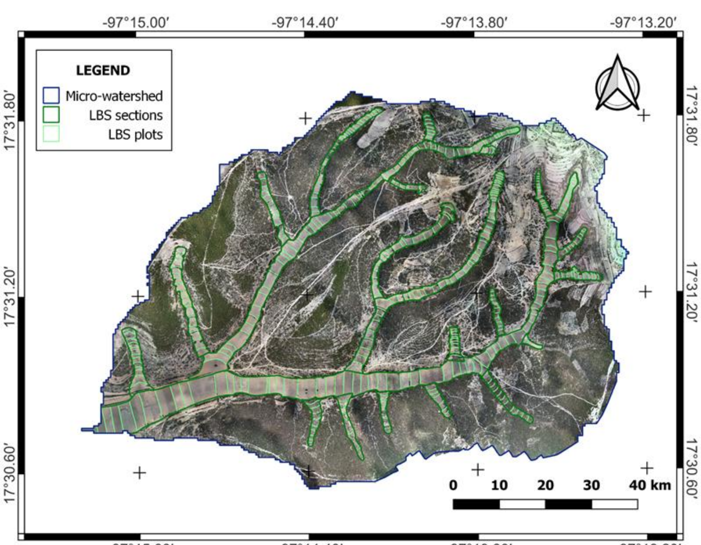

Figure 5. Lama-bordo system (LBS) sections and plots.

Estimation of OC and SOC_{30} at the sampling sites

According to the analysis of soil samples collected within (samples 1-14) and in surrounding areas (samples 15-27) of the study site (Table 2), OC content ranged from 0.39% to 2.00%, with a mean value of 0.98%. These values are lower than those reported by Holdridge and Leigh (2018), who found 1.10% to 2.44% OC in forest and grassland soils of the same region. These results are similar to those reported by Djuma et al. (2020), who found 1.7% for forests and 1.0% for agricultural lands. The use and management of soil determine the amount of SOC that can be accumulated (Ramesh et al., 2019).

Table 2. Measured and estimated parameters for the soil samples. OM: Organic matter; BD: soil bulk density; OC: organic C; SOC_{30}: soil organic C content at 30 cm.

Sample	OM	BD	OC	SOC_{30}
	%	g cm^{-3}	%	Mg ha^{-1}
1	1.08	1.71	0.63	31.81
2	1.08	1.43	0.63	26.60
3	1.34	1.71	0.78	40.01
4	0.67	1.50	0.39	17.55
5	1.75	1.39	1.02	42.12
6	1.08	1.55	0.63	28.83
7	1.21	1.48	0.70	31.08
8	0.67	1.30	0.39	15.21
9	2.15	1.32	1.25	49.50
10	0.94	1.52	0.55	25.08
11	1.34	1.53	0.78	35.80
12	1.61	1.39	0.93	39.20
13	2.29	1.35	1.33	53.87
14	0.94	1.43	0.55	23.60
15	2.42	1.36	1.40	57.12
16	2.02	1.53	1.17	53.70
17	2.69	1.50	1.56	70.20
18	1.08	1.51	0.63	28.09
19	0.67	1.54	0.39	18.02
20	2.15	1.42	1.25	53.25
21	2.96	1.27	1.72	50.67
22	2.29	1.31	1.33	52.27
23	3.23	1.50	1.87	84.15
24	0.94	1.54	0.55	25.41
25	2.07	1.25	1.20	45.00
26	2.24	1.15	1.30	44.85
27	3.45	1.15	2.00	69.00
Minimum	0.67	1.15	0.39	15.21
Maximum	3.45	1.71	2.00	84.15
Mean	1.72	1.43	0.98	41.18
SD	0.81	0.14	0.45	17.36
CV, %	47.19	9.88	46.10	42.16

Specifically, for the sampling points within the LBS, the mean OC content within the LBS was 0.75%, higher than the 0.58% reported for alluvial terraces by Ferguson et al. (2020). For SOC_{30} (at 30 cm), values across all sampling points (27) ranged from 15.21 to 84.15 Mg ha^{-1}, with a mean of 41.18 Mg ha^{-1}. Within the LBS (samples 1-14), SOC_{30} ranged from 15.21 to 53.87 Mg ha^{-1}, which, according to the classification of Mesías-Gallo et al. (2019), corresponds to categories from very low to very high, respectively. This indicates high variability in SOC content, which is typical of the heterogeneous behavior of soils in this type of terrace system. For instance, Xu et al. (2015) conducted a study across different land uses, sampling soils from terraces at a depth of 0-60 cm, and reported an SOC content of 44 Mg ha^{-1}, which is higher than the mean of 32.88 Mg ha^{-1} observed in the LBS. In the same study region (Mixteca Alta of Oaxaca).

Interpolation of SOC_{30} in the LBS

The interpolation of SOC_{30} data showed that the 0-30 cm soil layer has the potential to store between 3059.86 and 4156.28 Mg across the 104 ha that comprise the LBS area, corresponding to 29.42-39.96 Mg ha^{-1}. Table 3 presents the ranges and areas for each section of the LBS.

Table 3. Soil organic C content at 30 cm (SOC_{30}) for each lama-bordo system section.

Section	Class	Ranges of SOC_{30} classes		Area	SOC_{30} content	
		Mg ha^{-1}		ha	Mg	
1	1	15.22	20.00	1.93	29.31	38.54
	2	20.00	30.00	11.30	226.18	339.09
	3	30.00	40.00	27.40	822.27	1096.00
	4	40.00	53.83	2.26	90.45	121.76
2	2	20.00	30.00	0.00	0.04	0.06
	3	30.00	40.00	1.65	49.45	65.91
3	2	20.00	30.00	0.13	2.62	3.93
	3	30.00	40.00	1.70	50.98	67.95
4	3	30.00	40.00	1.19	35.73	47.63
5	3	30.00	40.00	1.33	39.84	53.10
6	2	20.00	30.00	2.02	40.49	60.70
7	1	15.22	20.00	0.06	0.94	1.24
	2	20.00	30.00	0.36	7.19	10.78
8	2	20.00	30.00	0.67	13.32	19.96
	3	30.00	40.00	0.85	25.48	33.96
9	3	30.00	40.00	1.00	30.10	40.12
10	4	40.00	53.83	1.12	44.70	60.17
11	2	20.00	30.00	1.05	21.09	31.62
	3	30.00	40.00	0.13	3.88	5.17
12	3	30.00	40.00	1.38	41.49	55.30
13	3	30.00	40.00	6.42	192.65	256.78
	4	40.00	53.86	3.51	140.24	188.78
14	3	30.00	40.00	1.91	57.21	76.25
	4	40.00	53.83	2.37	94.81	127.63
15	2	20.00	30.00	3.79	75.75	113.56
	3	30.00	40.00	8.99	269.69	359.47
	4	40.00	53.83	4.15	166.04	223.52
16	3	30.00	40.00	0.45	13.61	18.14
	4	40.00	53.83	0.32	12.97	17.46
17	4	40.00	53.83	0.47	18.70	25.17
18	2	20.00	30.00	0.28	5.68	8.51
	3	30.00	40.00	0.63	18.85	25.13
19	4	40.00	53.83	3.23	129.41	174.21
20	3	30.00	40.00	2.25	67.47	89.93
	4	40.00	53.83	0.14	5.79	7.79
21	2	20.00	30.00	1.13	22.58	33.86
	3	30.00	40.00	3.19	95.79	127.68
22	3	30.00	40.00	3.24	97.09	129.41
			Total	104.00	3059.86	4156.28

Figure 6 illustrates the spatial distribution of SOC_{30} within the LBS. Terraces located at higher elevations exhibit the greatest SOC_{30} concentrations, whereas the lowest values are found in the main section (Section 1). According to a study by Li et al. (2015), soil OM content was positively correlated with elevation, with higher altitudes showing greater values. Similarly, Xin et al. (2016) confirmed this relationship for SOC content in a watershed.

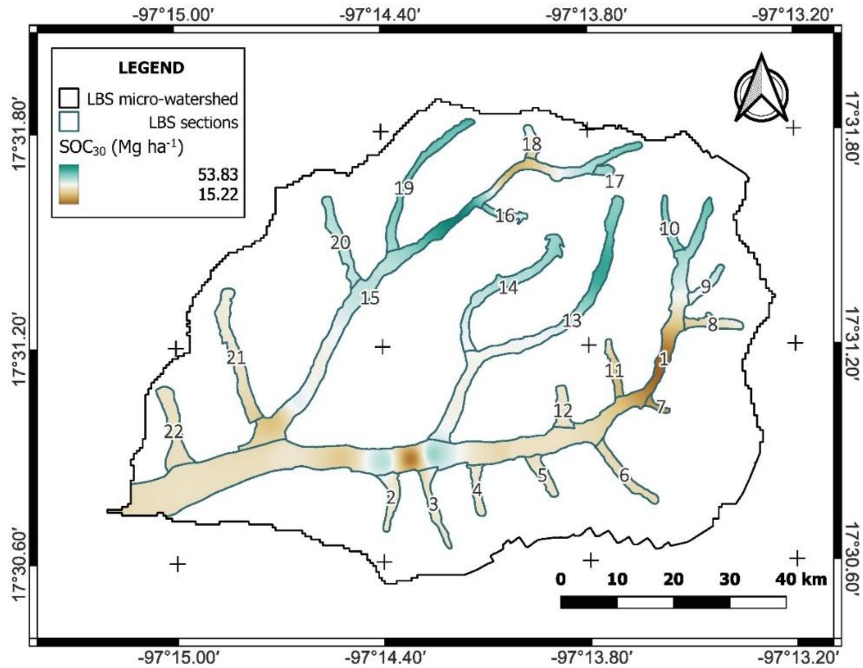

Figure 6. Distribution of soil organic C within the lama-bordo system (LBS) at the 0-30 cm soil layer (SOC_{30}).

Estimation of SOC_T in the LBS

Based on the studies conducted by Ferguson et al. (2020), SOC content in alluvial terraces varies heterogeneously with depth: It decreases away from the surface but later increases, leading to higher concentrations in both the topsoil and the deepest strata. For this reason, in the present study the estimated SOC_{30} value was assumed constant across the different depths of the terrace sections, ranging from 219.14 to 964.29 cm. Regarding SOC in the LBS (SOC_T) behavior for each LBS section, values ranged from 26 507.56 to 46 766.81 Mg across 104 ha, equivalent to 254.88 to 449.68 Mg ha^{-1}, as shown in Table 4. Mayer et al. (2018) state that large amounts of OC can be stored in soils at depths greater than 30 cm, and that its storage does not necessarily decrease with depth.

For total SOC, the pattern of spatial distribution changes due to the effect of the mean depth of each section (Figure 7). The main part of the LBS (Section 1) exhibits the lowest SOC content, likely due to its shallow depth and greater length; in contrast, Sections 3 and 16 hold the highest SOC storage.

The effect of the depth of each LBS section and the capacity of these systems to store sediments can be clearly observed. This capacity provides multiple benefits, including the recovery of eroded soil particles, the storage and conservation of water, the creation of suitable surfaces for agriculture, and the sequestration of SOC. The latter has gained increasing importance in recent years due to the environmental challenges caused by greenhouse gases. It also contributes to mitigating soil degradation, a severe regional problem, by improving soil properties. The SOC is essential for maintaining soil quality, restoring degraded ecosystems, ensuring food security, and reducing CO_2 emissions in the context of global warming (Chen et al., 2020). Furthermore, SOC influences most soil physicochemical properties, including nutrient availability, water holding capacity, and infiltration rate (Adeniyi et al., 2024). Equally important is the role of soils in enhancing C storage and their direct implications for climate change (He et al., 2025). Overall, degradation processes caused by the progressive abandonment of land reduce the effectiveness of terraces in providing these benefits (Socci et al., 2019).

Table 4. Total soil organic C content (SOC_T) for each section of the lama-bordo system (LBS). DeS: Mean depth of each LBS section.

Section	DeS	Class	Ranges of SOC_T classes		Area	SOC_T content	
	cm		Mg ha^{-1}		ha	Mg	
1	219.14	1	111.10	300.00	41.212	4578.62	12363.52
		2	300.00	500.00	1.612	483.58	805.97
2	500.50	3	500.00	700.00	1.662	831.02	1163.43
3	964.29	5	900.00	1100.00	1.743	1220.01	1568.58
		6	1100.00	1268.21	0.080	87.75	101.17
4	492.29	3	500.00	700.00	1.205	602.39	843.34
5	327.57	2	300.00	500.00	1.344	403.05	671.75
6	369.27	2	300.00	500.00	2.036	610.68	1017.81
7	435.67	1	111.10	300.00	0.152	16.93	45.71
		2	300.00	500.00	0.266	79.90	133.17
8	480.25	2	300.00	500.00	1.016	304.68	507.81
		3	500.00	700.00	0.532	266.00	372.40
9	431.50	2	300.00	500.00	0.250	74.95	124.91
		3	500.00	700.00	0.768	383.97	537.55
10	234.29	2	300.00	500.00	1.114	334.26	557.10
11	349.64	1	111.10	300.00	0.664	73.76	199.18
		2	300.00	500.00	0.514	154.10	256.83
12	264.64	1	111.10	300.00	1.378	153.04	413.25
13	285.49	2	300.00	500.00	9.993	2997.84	4996.40
14	435.84	3	500.00	700.00	4.281	2140.62	2996.87
15	288.26	1	111.10	300.00	4.073	452.48	1221.83
		2	300.00	500.00	12.144	3643.22	6072.03
		3	500.00	700.00	0.601	300.74	421.04
16	815.33	5	700.00	900.00	0.494	345.92	444.75
		6	1100.00	1268.21	0.299	328.48	378.71
17	560.00	4	700.00	900.00	0.475	332.35	427.30
18	313.00	1	111.10	300.00	0.169	18.73	50.58
		2	300.00	500.00	0.739	221.84	369.73
19	366.08	2	300.00	500.00	0.071	21.42	35.70
		3	500.00	700.00	3.148	1574.05	2203.67
20	463.33	3	500.00	700.00	2.404	1202.17	1683.03
21	450.25	2	300.00	500.00	4.328	1298.33	2163.89
22	470.00	2	300.00	500.00	3.236	970.66	1617.77
				Total	104.00	26507.56	46766.81

Several factors determine SOC storage in different soil types, including soil depth, slope, rock exposure, clay content, water-holding capacity, nutrient stocks, and landscape position (Lal, 2018; Zhang et al., 2019). In contrast, soils that store the least SOC are characterized by being eroded, degraded, desertified, and depleted (Lal, 2018). Because the LBS is a surface formed within drainage channels through the erosion and deposition of soil from upslope areas and lateral slopes, it has a minimal slope that limits particle movement and provides stability to the system, further enhanced by stone walls. In this context, the LBS conserves a substantial volume of soil that, although containing relatively low SOC amounts in the present study, makes an important contribution by maintaining this resource in a stable state. However, not all sections comprising the LBS behave in the same way. While some concentrate relatively high amounts of SOC, others show considerably lower values, resulting in a wide range of SOC storage within the system itself. This range can be explained by differences in depth among terrace sections, which have been recognized in the literature as one of the most influential predictors of the accuracy and variability of SOC estimates (Li et al., 2024). Indeed, uncertainty associated with the quantification of C stocks tends to increase as the depth of the soil profile considered increases (Maillard et al., 2017).

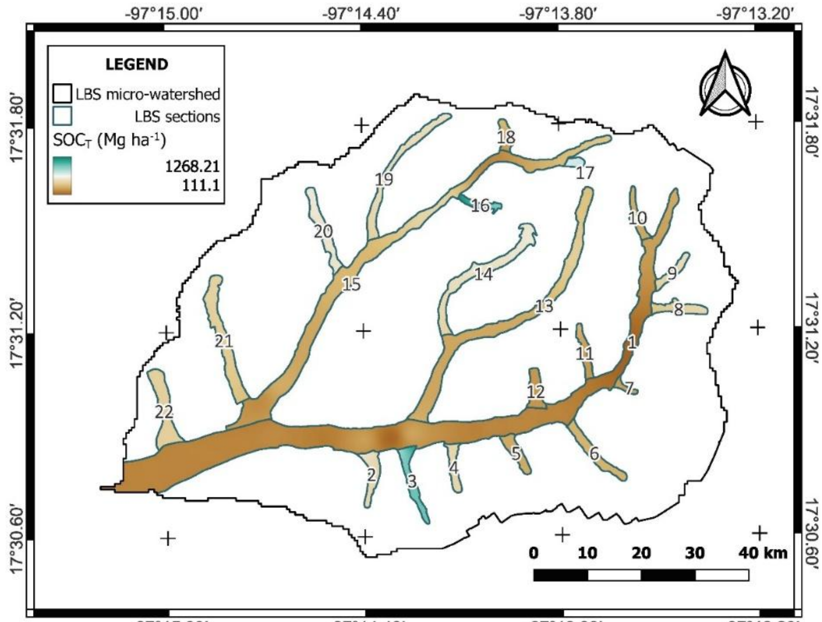

Figure 7. Spatial distribution of soil organic C in the lama-bordo system (LBS) (SOC_T) at the mean depth of each section.

CONCLUSIONS

Alluvial agricultural terraces, such as the lama-bordo system, contribute to soil recovery, water retention, provision of suitable surfaces for agriculture, and function as reservoirs of soil organic C (SOC). Although SOC storage on terraces has been little studied, it has gained significant importance in recent decades due to the global challenge of greenhouse gas emissions. In the study area, the potential SOC storage resulting from the depth of the terraces comprising the system ranged from 254.88 to 449.68 Mg ha^{-1}, with an estimated total SOC stock of 26 507.56 to 46 766.81 Mg. These values are higher than those reported in other studies for the region and contribute to maintaining soil quality, restoring degraded ecosystems, and supporting food security. Further research on these terraces is essential, given their long-standing presence in the Mixteca Alta region of Oaxaca and their direct contribution to ecosystem services

Author contribution

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