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Terracing Increases Organic Carbon Content in the Loess Plateau

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Abstract

Aim: Terracing is widely distributed in mountainous and hilly areas around the world and can be effective in inhibiting soil erosion, increasing soil moisture, improving soil quality and potentially having a positive impact on soil carbon pools.

Methods: To understand the impact of agricultural activities and ecological restoration measures on changes in soil carbon pools in terraced areas, we set up an observation system in typical terraces on the Loess Plateau and soil samples were

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gathered from 0-100 cm depth in terraces (containing different crops and different ecological restoration vegetation) and slopes.

Results: The results show that terracing can effectively increase soil organic carbon (SOC) content (7.7 g·kg-1 in terraced cropland > 4.9 g·kg-1 in sloping cropland). Changes in the organic carbon content of the terracing is mainly due to improvements in soil and water conservation capacity and agricultural activities, loss of soil organic carbon due to short-term abandonment and an increase in soil organic carbon due to replanting of fruit trees and crops. The choice of tree species in afforestation policies has also led to differences in soil organic carbon. Pinus tabuliformis Carr. has the highest SOC content (9.8 g·kg-1).

Conclusions: The SOC content in 0-100 cm of terraced fields planted with wheat was 1.5 times higher than that of sloping fields planted with wheat. Compared with sloping land, terrace construction significantly increased the SOC content of cultivated land, especially in the top soil layer (0-30 cm), and converting some sloping land into terraces would enhance the carbon sequestration capacity. This study has significant implications for agricultural management and ecological restoration in the terraced areas of the Loess Plateau and contributes to the development of rational policies for carbon sequestration on arable land in terraced areas.

Keywords: Terracing; Soil Organic Carbon; Agricultural activities; Vegetation cover

1 Introduction

Soil is considered to be the second largest carbon reservoir next to the ocean

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(Stockmann et al., 2013), and the soil carbon reservoir is crucial for the global carbon cycle (Lal, 2004; Houghton, 2007). SOC is is a key element of the global carbon cycle (Rossel et al., 2019) and serves as a significant indicator for assessing soil quality and land productivity (Guillaume et al., 2021; Wang et al., 2012). To address climate change and lower CO2 emissions for sustainable development, we should sequester more carbon in the soil rather than releasing it into the atmosphere. This is already an urgent and challenging issue for humanity (Bednar et al., 2021). Therefore, understanding the variation of SOC content in different regions, especially in anthropogenic landscapes, is of great importance to assess the carbon sequestration potential of soils and mitigate climate change. The sequestration of large amounts of CO_2 into soils can be achieved by the ways of land use and management practices policies (Smith, 2012). However, SOC reserves have been declining worldwide (Jones et al., 2005). Forest destruction caused by reclaiming farmland is the main reason for global SOC consumption to date, resulting in increasingly serious ecological damage (Lal, 2016). Hence, how to increase soil organic carbon to maintain soil quality, restore ecology, ensure food security and reduce CO2 emissions is a matter of great concern in the context of global warming.

Agricultural terracing is a crucial landscape engineering measure to reduce soil erosion and maintain soil fertility and increase agricultural productivity (Doetterl et al., 2012; Zhu et al, 2021), which is one of the ways to achieve sustainable agricultural development. On the one hand, the conversion of terraces into slopes increases the cultivated area significantly. On the other hand, it helps prevent erosion problems

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(Arnáez et al., 2015) and effectively increases food production (Tarolli et al., 2014). Terraces are widely distributed and have created environmental benefits in countries in East Asia, the Mediterranean, and Southeast Asia (Wei et al., 2016). Many studies have shown that terracing can intercept more than 80% of rainfall runoff and sediment, and horizontal terracing can retain all rainfall to replenish soil moisture. The positive benefits of carbon capture generated by terraces come from the collection of eroded material for sloping soils. However, the conversion of natural vegetation to cropland inevitably results in a reduction of biomass and therefore a significant loss of SOC (Aguilera et al., 2018 and 2013). During the construction of terraces period, it is inevitable stripping of topsoil and exposure of deep soil, and a large amount of new subsoil covers the surface of the terraces. This severe soil disturbance may alter soil organic carbon dynamics (Sidle et al., 2006), but the potential long-term benefits of terrace construction are considerable (Chen et al., 2017). However, many terraces are experiencing ridge damage and terrace collapse due to a lack of terrace maintenance or land abandonment, which not only leads to reduce soil and water conservation benefits but potentially increases erosion and carbon emissions (Arnáez et al., 2015; Wen et al., 2020).

Agricultural land accounts for more than 30% of the global area and has great potential for carbon sequestration and mitigation of global climate change (Sun et al., 2010). Agricultural soils can be improved by implementing some regulatory management practices to improve soil properties and further increase organic carbon content (Lal et al., 2011). However, studies from different regions have shown a global trend of decreasing organic carbon content in agricultural soils nowadays (Bellamy et al. 2008; Heikkinen et al. 2013; Yli-Halla et al., 2018). How to increase the SOC content of farmland is the key to promoting sustainable agriculture and improving the carbon sink. In the Loess Plateau region, a large amount of arable land has been converted to woodland and grassland through the implementation of afforestation and reforestation policies, and these measures have increased the organic carbon content of the soil (Rong et al., 2021). In the implementation of ecological restoration, different vegetation types have different benefits in increasing soil carbon pools (Hong et al., 2020). The agroforestry cropping pattern with other crops stores more carbon than other traditional agricultural cropping patterns (Smith et al., 2022). Nair et al. (2009) cited seven studies on soil carbon in tropical agroforestry systems that show that this type of cropping certainly stores more carbon.

In the Loess Plateau, the erosion problem of sloping land has a great impact on agricultural production (Ran et al., 2020). Terracing has become the most important ways to solve the erosion problem on sloping lands. By the end of 2012, there were 37,100 km^2 of terraced fields on the Loess Plateau. With the further development of terrace construction, changes in surface morphology and soil properties also lead to dynamic changes in soil carbon pools, and such changes will lead to changes in soil carbon storage capacity. Meanwhile, how the land use pattern of terraces and human activity factors such as abandonment and crop type affect the soil carbon pool of terraces still needs to be investigated. The implementation of afforestation policies in terraced areas will also lead to changes in soil carbon pools. Consequently, we

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gathered soil samples from terraces and slopes, including terraces with varying land use and crop types, to investigate (1) the impacts of terrace construction on SOC in the Loess Plateau region and (2) the effects of different vegetation cover and tillage activities on the carbon sink capacity of terraces. This study will provide a reference for terrace management and is also a guide for soil carbon sequestration.

2 Data and Methods

2.1 Study Area

The study area is the typical terrace construction region of the Loess Plateau (Zhuanglang terracing) and the construction of this area began in the 1960s. By 2005, 14790 km^2 of terraces have been built, accounting for 95.3% of the total arable land in the region. The structure of the terraces is mainly horizontal terraces. Zhuanglang terraces belong to the loess hilly terrain area with gullies and complex topography, and the elevation is between 1521m-1784m. The climate type is temperate continental, with warm, humid summers and cold, dry winters. More than 60% of precipitation occurs in summer and autumn (July - October), with an annual rainfall of 542mm and an average annual temperature of 7.5℃. The dominant soil type in this area is fine loessial soil, the natural vegetation is mainly herbaceous, shrubs, coniferous forests, and locust trees, and the crops are wheat, maize, potatoes, and apple trees. Due to the constraints of soil properties and irrigation water sources in this region, the growth of crops depends on natural rainfall.

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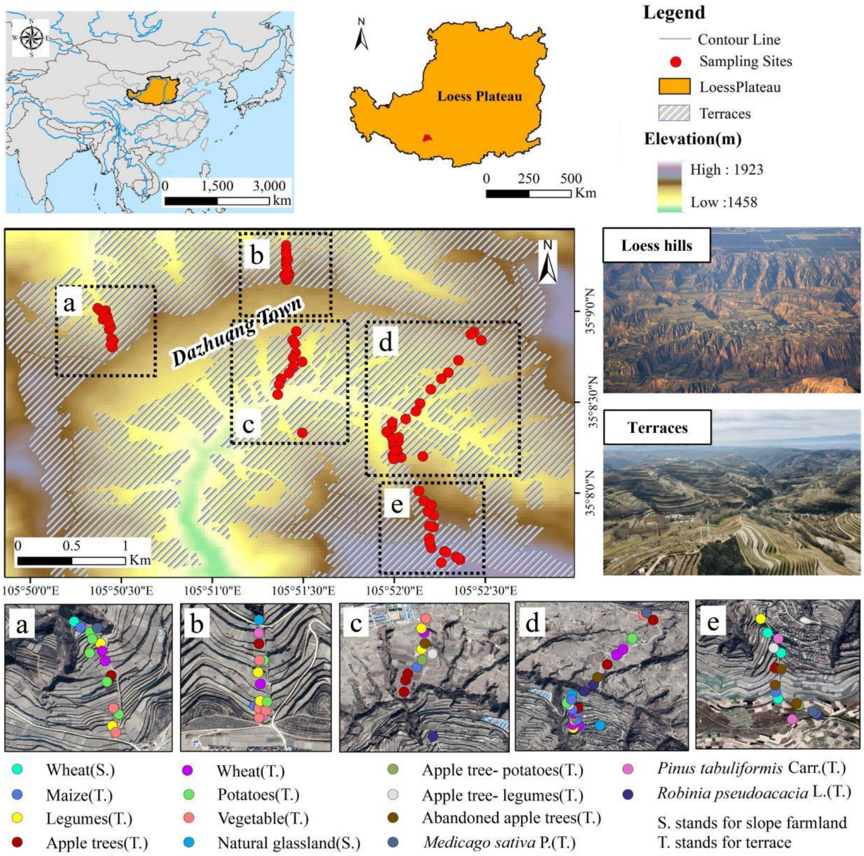

Fig.1 Study area

2.2 Terraced soil sample collection

We carried out soil sample collection at the terrace observation system in Yangpota mountain, Dazhuang Town, Zhuanglang County, with the sampling date being October 2020. The construction of terraces in this area started in 1964 and based on interviews with local farmers, it was confirmed that all the agricultural fields in the area had been constructed in 1991, and all the terraces were constructed 30 years ago. The main terracing structure built in the region is the horizontal terrace, which is an agricultural field with stepped sections along contours on the slopes of loess hills. The width of the terraces varies from 1.6 to 6 meters, and the height of the terrace steps varies from 0.3 to 0.8 meters. The terraced slopes are slightly counter-sloped to collect more precipitation and the slope ranges from 0% to 11% (Chen et al., 2020).

We randomly set up 84 sampling sites in the study area, with 77 terraced sampling sites and 7 slope sampling sites. Crop type, cropping pattern, and agricultural abandonment all affect the soil carbon pool of the terraces, so the terraces included sampling points for different cropping patterns of apple trees (9), number of sampling points), vegetable (9), wheat (9), legume (9), potato (9), maize (9), apple tree-legume (3) and apple- potato (3) (Appendix, Fig. A1). Five abandoned apple tree terraces were included in the terraces and the apple trees were not removed from the terraces and there was a large amount of weed growth. Three types of restored vegetation were planted on the terraces: *Robinia pseudoacacia* L. (4), *Pinus tabuliformis* Carr. (4) and *Medicago sativa* L. (4). The seven slope sites included four wheat plantations and three natural grassland sites (Table 1).

Measuring SOC concentrations in the surface layer of the soil (10 or 20 cm) alone does not imply soil changes due to tillage management, so we designed the sampling depth as 1 m. Samples were collected at 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm, 70-80 cm, 80- 90cm, and 90-100cm samples. A (2 × 2) m^2 sample square was randomly delineated in each identified sample plot and sampled along the diagonal line. The soil samples collected three

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times were mixed according to different soil layers after removing plant roots and debris, and 840 mixed soil samples were finally obtained.

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Table1 Number of different types of sampling plots, vegetation types, number of samples, and soil property data

Land types	Planting method	Vegetation types	Number of soil profiles	Soil depth(cm)	Soil texture fractions			Soil moisture(%)		SOC(g•kg^{-1})	
					Clay (%)	Silt (%)	Sand (%)	Mean	SD	Mean	SD
Terrace	Single vegetation	Wheat	9	0-100	11.1	80.9	8.0	24.2	10.36	7.7	2.78
		Apple trees	9	0-100	—	—	—	24.3	9.32	7.1	2.39
		Potatoes	9	0-100	—	—	—	26.8	12.98	5.2	2.32
		Legumes	9	0-100	—	—	—	23.2	15.21	4.5	2.10
		Maize	9	0-100	—	—	—	21.4	10.35	7.7	2.48
		Robinia pseudoacacia L.	4	0-100	10.8	79.4	9.8	18.2	5.92	8.0	2.77
		Pinus tabuliformis Carr.	4	0-100	9.9	84.0	6.1	19.3	6.33	9.8	4.44
		Medicago sativa L.	4	0-100	10.9	80.0	9.1	20.4	13.62	5.6	1.57
		Vegetable	9	0-100	—	—	—	22.1	5.31	6.5	1.80
	Multiple vegetation	Apple tree-legumes	3	0-100	—	—	—	20.2	7.36	5.4	1.65
		Apple tree-potatoes	3	0-100	—	—	—	22.7	10.68	6.7	1.77
Sloping land	Single vegetation	Wheat	4	0-100	10.0	78.0	12.0	21.3	13.44	4.9	1.07
		Grassland	3	0-100	10.4	80.1	9.5	21.0	9.62	6.0	2.26
Abandoned terraces	Multiple vegetation	Apple trees and weeds	5	0-100	10.6	78.5	10.8	23.7	11.35	6.4	1.85

Note: "—" represents not measured. All soil attribute data values are average values, average soil texture, soil moisture, and SOC of the 0-100 cm profiles, derived from 10 samples for each profile (10-cm depth intervals)

2.3 Experimental analysis and data statistics

The collected soil samples were placed in sealed plastic bags and pre-weighed aluminum boxes. The soil samples in the aluminum box were dried in the bake oven at 105 °C for 24 hours to measure the soil moisture. After the samples were completely shade-dried in the laboratory, gravels and plant roots were removed from the samples using a sieve with a particle size of 2 mm. A 0.2 g soil sample was weighed and the concentration of SOC was measured using a wet oxidation method with dichromate (Nelson and Sommers, 1982). The soil texture, including sand, silt, and clay content, was analyzed through a laser diffraction technique utilizing a Mastersizer 2000 (Malvern Instruments, Malvern, England).

All data in this paper were analyzed by SPSS 21 statistical software. All collected data underwent normality testing using the Kolmogorov-Smirnov test and were assessed for homogeneity of variance with Levene's test, ensuring $P > 0.05$. Comparative analysis of various sample point types was performed utilizing a one-way ANOVA, with significance considered at $P \leq 0.05$.All data are expressed as means ± standard deviation. Graphs were made using Origin 2021 software.

3 Results

3.1 SOC characteristics of different land use types

The SOC content of the abandoned apple tree terraces were lower than that of the in-use apple tree terraces, but the difference was small at 0.7 $g \cdot kg^{-1}$. The SOC content of the wheat-grown sloping fields was significantly lower than that of the wheat-grown terraces, with the SOC content of the terraces being 1.5 times higher than that of the sloping fields, with a difference of 3.8 $g \cdot kg^{-1}$ between the two (7.7 $g \cdot kg^{-1}$ > 4.9 $g \cdot kg^{-1}$). The SOC content of natural grassland was slightly higher (6.0 $g \cdot kg^{-1}$ > 5.6 $g \cdot kg^{-1}$) compared to planted grassland, although natural grassland with weeds had not been terraced. Slopes with natural vegetation were higher in SOC (6.0 $g \cdot kg^{-1}$) than those under cultivation (4.9 $g \cdot kg^{-1}$) (Table 1).

The vertical variation of SOC at 0-100 cm depth varied significantly among land use types (Fig. 2). Except for the abandoned land, all land use types showed an irregular decreasing change pattern from the surface layer to the deep layer of the soil. In the 0-10cm soil layer, the highest SOC content was found in terraces planted with wheat and the lowest SOC content was found in terraces planted with *M. sativa*. Terraces planted with fruit trees had significantly higher SOC content at 80-100cm depth than terraces planted with crops, *M. sativa,* and natural grassland. The vertical variation of SOC in sloping fields and terraces planted with wheat was consistent, with their greatest SOC content occurring at 0-20 cm depth and their smallest SOC content at 90-100 cm depth. In the abandoned terraces, SOC varied between 0-80 cm, with the smallest SOC content occurring in the 80 cm soil layer.

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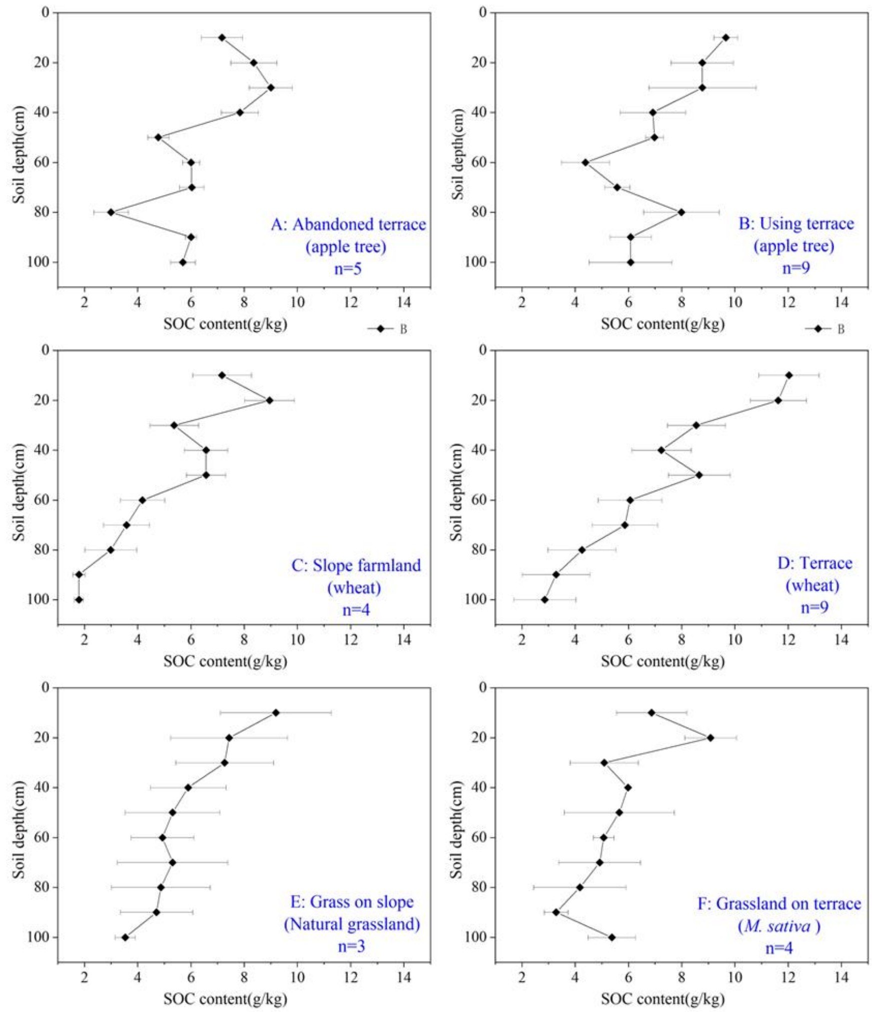

Fig.2 SOC Vertical variation of SOC content by land use type
Bars denote the standard deviation of the mean, n represents the number of soil profiles.

3.2 Characteristics of SOC in terraces of different planting patterns

Differences in SOC were smaller in terraces planted with apple trees and greater between terraces planted with a single crop. Among all crop types, legumes had the lowest SOC content (4.5 $g·kg^{-1}$) and maize had the highest SOC content (7.7 $g·kg^{-1}$).

The SOC content of concurrent apple tree - legumes and apple tree - potatoes was higher than that of legumes and potatoes grown alone (5.4 g·kg^{-1} > 4.5 g·kg^{-1} and 6.7 g·kg^{-1} > 5.2 g·kg^{-1}) (Table 1).

The vertical distribution of SOC content across a depth of 0-100 cm showed a consistent decline from the surface soil to the deeper layers for all crops. The SOC content (15.1 g·kg^{-1}) of wheat cultivated terraces was the highest among all crops at the soil surface (0-10 cm). Terraces planted with apple trees, maize, or wheat had higher SOC content in deeper soils (30-100 cm). Beans and potatoes had lower SOC content at 50-100 cm depth than terraces planted with other crops. The difference in SOC content between potato terraces planted alone and apple tree-potato terraces at 0-20 cm depth was not significant. However, below 20 cm depth, the SOC content of the apple tree-potatoes combination was significantly higher than that of the terraces planted with potatoes alone. This difference is also reflected in the legumes and apple tree-legumes (Fig.3).

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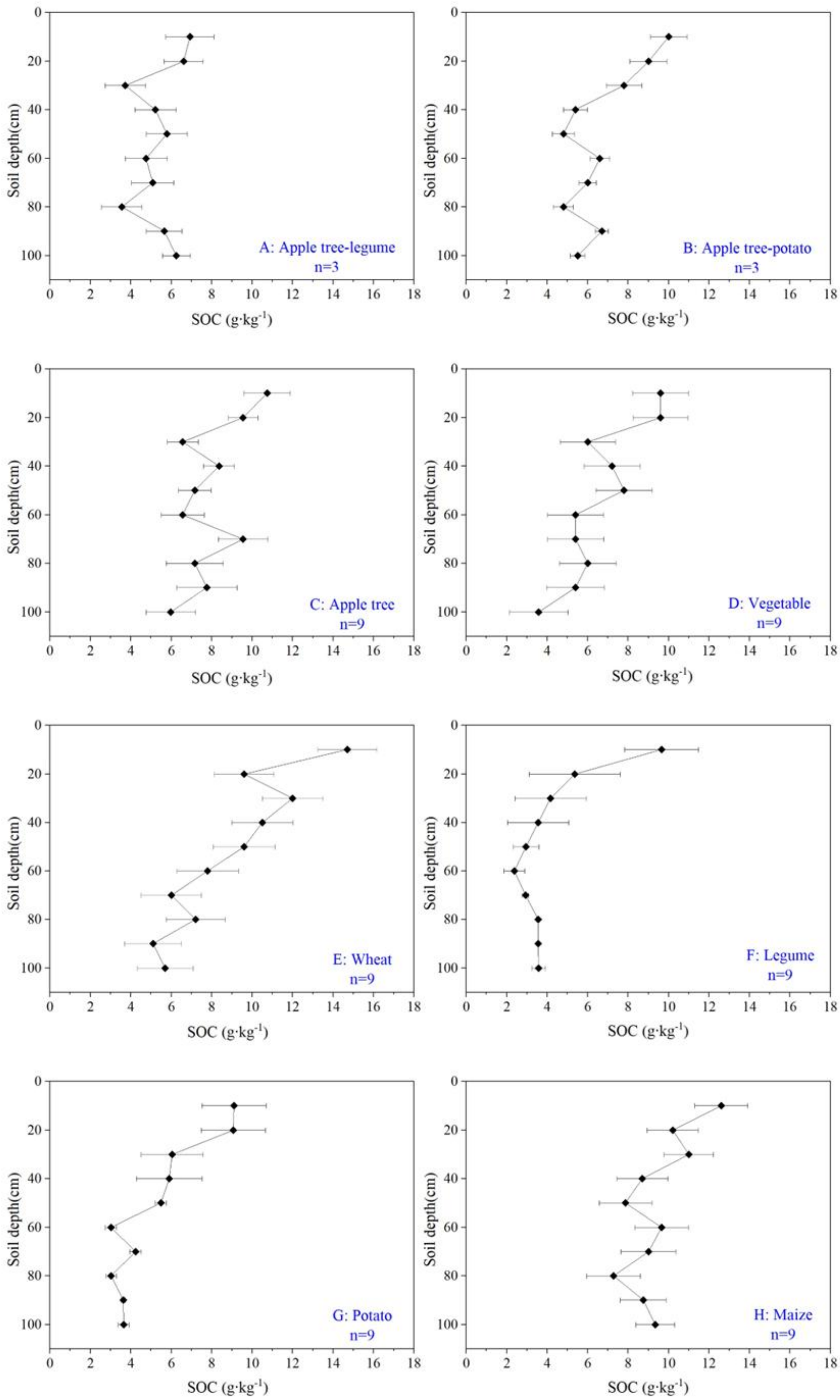

230 Fig.3 Vertical distribution of SOC content in different crop types

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Bars denote the standard deviation of the mean, n represents the number of soil profiles.

3.3 Characteristics of SOC in terraces with different ecologically restored vegetation

Comparing the SOC characteristics of the three types of ecologically restored vegetation after terracing, the average SOC content of terraces planted with trees 0-100 cm was higher than that of terraces planted with forage (Table 1). This difference varied at different depths, with the SOC content of alfalfa being significantly lower than that of the two trees in the 0-10 cm soil surface layer, becoming smaller in the 10-20 cm depth, but increasing again in the 20-60 cm depth. At 70-100 cm depth this difference became smaller and the SOC content between the three vegetation species became close.

The difference in SOC between different silvicultural species was higher in *P. tabuliformis* than in *R. pseudoacacia* at 0-100 cm depth, with a difference of 1.83 $g \cdot kg^{-1}$. The significant difference in SOC between the two species was mainly at 0-70 cm depth, where *P. tabuliformis* had a higher SOC content than *R. pseudoacacia*. The difference in SOC content between the two species became smaller at the depth of 70-100 cm, and the SOC content of *R. pseudoacacia* was slightly higher than that of *P. tabuliformis* (Fig.4).

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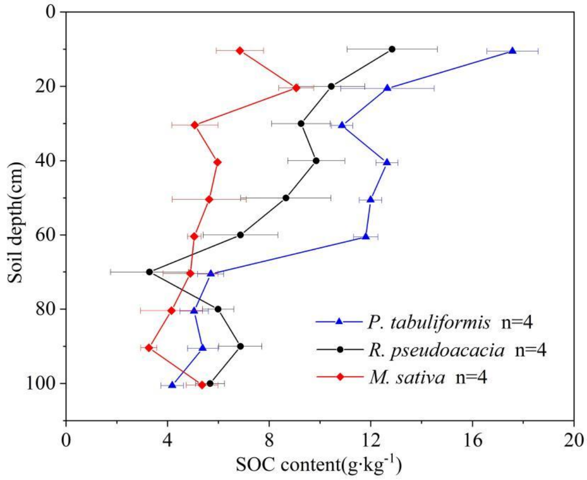

Fig.4 SOC vertical variation of different ecologically restored vegetation. Bars denote the standard deviation of the mean, n represents the number of soil profiles.

4 Discussion

4.1 Effect of terrace construction on SOC

In the Loess Plateau area, the average SOC content of terraces 0-100cm is 1.4 times higher than that of sloping farmland (Table 1). In Zhang et al. (2013), the SOC stock at 0-100 cm depth was 4.97 kg·m^{-2} in terraces and 3.09 kg·m^{-2} in sloping fields, which is 1.6 times higher than the soil organic carbon stock in sloping fields, which is consistent with the results of this study. Terracing is considered an important practice to prevent water erosion and minimize the loss of SOC (Nie et al., 2017). There is a positive feedback relationship between soil moisture and soil carbon (Green et al., 2019). Horizontal terraces are the most widespread terraces in the Loess Plateau, which has changed the surface morphology, increased the time of rainfall storage at the surface, and enhanced soil moisture in rain-dependent farming regions of the Loess Plateau (Xu et al., 2021). Ecological stress caused by soil water deficit leads to a decrease in biomass and net primary plant productivity. Conversely, an increase in soil water has a positive effect on biological growth (McDowell et al., 2015). The interception of precipitation on the terrace surface provides water for plant growth, increases plant biomass, and increases the organic matter put into the soil, thus having an impact on the SOC content. The interception of precipitation by the terraces means that precipitation will no longer carry large amounts of fine soil particles from the soil, which will increase the content of clay particles in the soil. Soil clay particles have a larger specific area, which can adsorb more soil organic carbon and enhance the accumulation of organic carbon (Post et al., 1982). Compared to sloping land, terraces have a higher content of both clay and silt in the soil. The terraces therefore further contribute to carbon accumulation in the terraces by protecting the fine particles in the soil. In a study on the Loess Plateau, the SOC content of 0-100 cm in unterraced date palm orchards was 2.6 $g{\cdot}kg^{-1}$, which was lower than the soc content of terraced orchards. This evidence further demonstrates the positive effect of terracing on soil organic carbon sequestration (Gao et al., 2017).

The SOC varies significantly in terms of the amount of plant and animal residues entering the soil and the depth of the soil under agricultural cultivation (Koga et al., 2020). The impact of agricultural activities on the surface soil levels was stronger compared to the deeper soil levels (Li et al., 2020). In this study, we observed a

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significant increase in SOC in terraces than in sloping lands, particularly in the 0-30 cm soil layer (Fig.5). Post-terracing, SOC sequestration in deeper soils lagged behind that in surface soils. Furthermore, the rate of SOC change was more pronounced in the surface layer (0-20 cm) compared to the deeper layer (20-100 cm). Precipitation in the region is limited and cannot replenish deep soil water, and the erosion of precipitation on the slope surface also mainly takes away the top soil layer. Therefore, the soil and water conservation effect brought by terrace construction is limited, so for the soil depth increases, this effect will become smaller. The impact of terracing on SOC sequestration diminishes as soil depth increases (Deng, Liu, and Shangguan., 2014). As soil depth increases, the water stored in the terraces cannot penetrate deeper soils and deeper soils will maintain their properties. Therefore, the management and conservation of terrace topsoil are important to ensure local food production and enhance the carbon sink function (Li et al., 2014).

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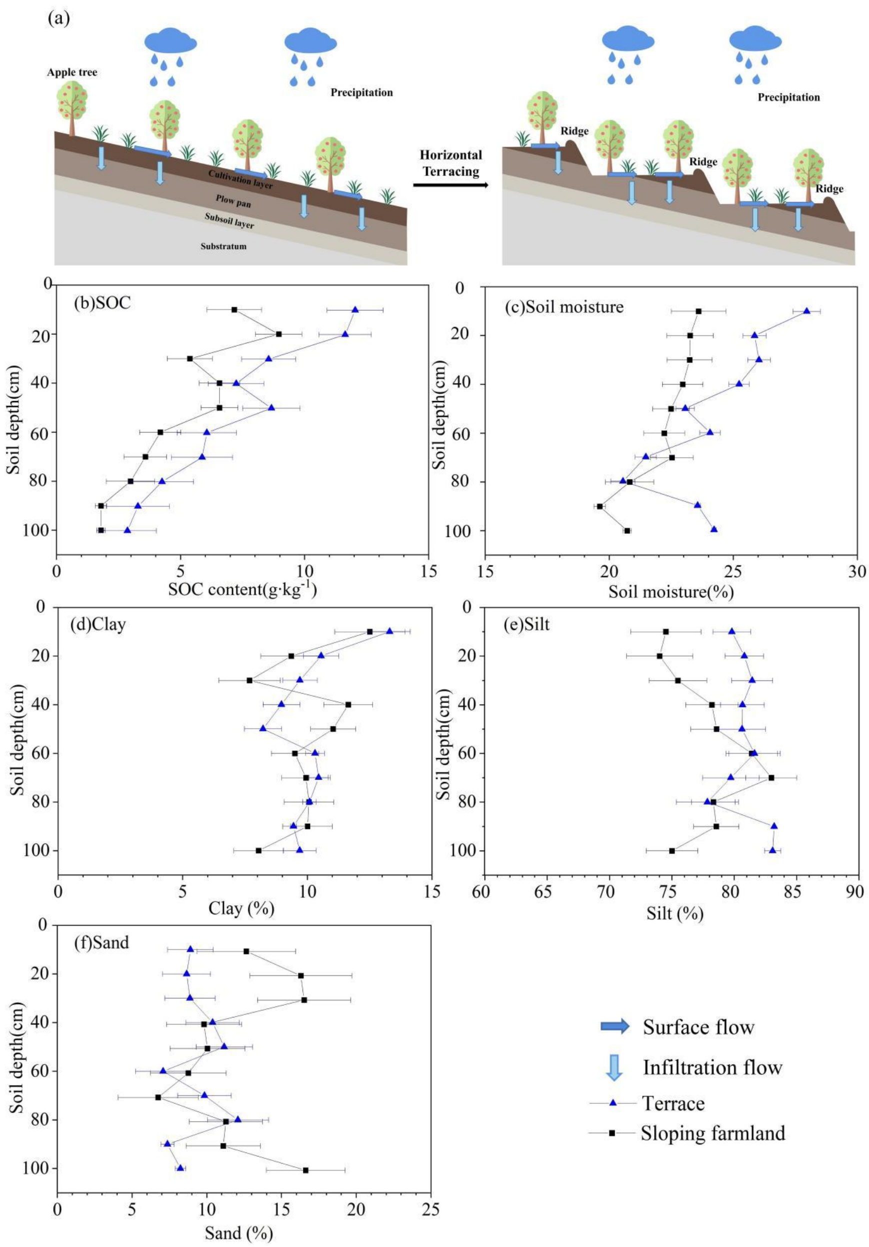

Fig.5 Effect of terrace construction on SOC, soil moisture, and soil grades.

(a): Variation in surface morphology by terrace construction; (b): variation in SOC content; (d): variation in soil moisture; (d), (e), and(f): variation in soil grades. The number of profiles is 9 for terraces and 4 for sloping fields. Bars denote the standard deviation of the mean.

4.2 Effect of terraces abandonment on SOC

As in other parts of the world, industrialization and urbanization have led to a large population flock from rural to urban areas as in China, resulting in the abandonment of a large number of productive potential farmlands (Wiesmeier et al., 2012; Cai et al., 2016). Moreover, a large amount of arable land in rain-fed agricultural areas in the Loess Plateau region has been abandoned due to water resource constraints or due to declines in soil fertility (Cao et al., 2020). Secondary succession of vegetation after terraces abandonment leads to an increase in soil carbon content as a potential pathway for climate change mitigation (Bell et al., 2021). When the terraced fields were abandoned in this research, the SOC content of the abandoned terraces was lower than that of the terraces in use. This is caused by the short abandoned time. To produce significant environmental benefits, the land must remain abandoned for an extended period to accumulate substantial amounts of both plant biomass and the species that constitute intact ecological communities. This process can take decades to reach levels of carbon sequestration or biodiversity comparable to those of undisturbed ecosystems (Crawford et al., 2022; Poorter et al., 2016). Due to the limited water resources available in semi-arid areas, a longer natural or assisted recovery time is required. Therefore, the duration of land abandonment is a crucial factor influencing the dynamic changes SOC (Djuma et al., 2020; Badalamenti et al., 2019). In related studies in other regions, soil carbon stocks increased by 13% and 16% in cropland abandoned for 15 and 35 years, respectively (Novara et al., 2014). With the abandonment of disposal time extended, vegetation types gradually transition to grassland, scrub, and forest and the death of plants and animals return to the soil as organic matter, increasing the number of soil aggregates and further increasing the carbon content of the soil (Liu et al., 2020). Therefore, ecological restoration of newly abandoned terraces should be carried out as soon as possible. After short-term abandonment, the terraced fields showed a special change pattern at different depths in this study. SOC content first decreased and then increased with increasing soil depth. The decrease in surface SOC was controlled by the decrease in agricultural fertilizer inputs, while the increase in deep SOC was caused by the inability to utilize deep soil nutrients due to the death of crop roots.

4.3 Effect of vegetation type and planting patterns on SOC in terraces

Vegetation types can influence SOC by modifying the soil's physicochemical structure and altering both the input and decomposition rates of SOC (Du et al., 2022; Wiesmeier et al., 2012; Wan et al., 2019). Our study demonstrated that, compared to terraced fields, the SOC content of afforested land at a 0-100 cm depth was higher and that the forest litter biomass was more than that of farmland, which was the main reason for this difference. Planted forest land reduces soil temperature, soil moisture evaporation, and soil erosion while increasing the quantity and quality of organic matter input to compensate for carbon decomposition from crop cultivation (Liu et al.,

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2020). The afforested land is terraced forests, and the effect of preventing soil erosion is more significant. Some study shows that the SOC in immature forests (10 years old) is 17.91% higher than that in terraced cropland. The SOC concentration of a 30-year-old forest is significantly higher than that in other land covers (Xin et al., 2016). These studies further proved the carbon sequestration effect of reforestation.

Due to the problem of ecological degradation and soil erosion, various ecological measures have been taken in the Loess Plateau area, such as returning farmland to forest and grass and planting trees (Hong et al., 2020). Considering the climate and soil quality factors, the main species selected in the Loess Plateau region are drought-tolerant types of trees, and the carbon accumulation effect of different species selection also differs significantly (Li et al., 2018). *P. tabuliformis* has a higher SOC content than *R. pseudoacacia*, especially in the 0-50 cm soil layer. The pine species selected in this region is larch, with the arrival of winter a large number of pine needles and fruits are into the soil, increasing the input of organic matter in the surface layer so that the SOC content of pine forests is higher in the surface layer of the soil (0-10 cm). In humid areas, some studies also show that the soil organic carbon density of fir conifer forests is the largest among the different 11 middle forest vegetation types (Chen et al., 2007). Other studies have shown that tree species such as *P. koraiensis*, *L. gmelinii,* and *P. tabuliformis* increase soil organic carbon stocks more as silvicultural species (Hong et al., 2020). The biomass of the herbaceous plants themselves is much lower than that of trees, and the limited amount of organic matter entering the soil, and the fact that *M. sativa* is mainly used as a source of fodder for the animals raised by farmers in the region, leads to a lower SOC content in terraces planted with *M. sativa* than in those undergoing afforestation.

The SOC content of grassland at a depth of 0-100cm is lower than that of farmland. Although the grassland has organic matter after the withered herbs enter the soil, the main planting type in the terrace area is apple trees, and a large amount of fruit tree leaves will also enter the soil. Grassland is a sloping land that has not been terraced, leading to slope erosion that removes a significant amount of organic matter from the soil surface. As a result, the SOC content in grassland is lower than in terraced fields (Fig.2). The ecological advantages of sequestering SOC and enhancing soil fertility could be significant, largely thanks to the widespread implementation of reforestation and various land use strategies in terraced fields across China and numerous other mountainous areas globally (Hong et al., 2020).

Crops may differ in their ability to increase SOC content due to differences in their photosynthetic capacity and root characteristics (Wegener et al., 2015). The pattern of intercropping in this area is typical of Agroforestry systems (AFS), where other crops are planted between the rows of apple trees. The SOC content of apple trees in combination with other crops was higher than in monocultures, especially in the lower and middle layers of the soil (30-100 cm). The amount of tree litter and root decomposition are important reasons for this (Pardon et al., 2017). The fallen leaves of fruit trees and some rotting apples are not removed, and these organic materials decompose to replenish SOC after entering the soil. In addition, carbon input can be achieved by decomposing (fine) tree roots and root secretions (Nair et al., 2009). For

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soils below 30 cm depth, tree roots produce an important role in the accumulation of soil organic carbon. When potato or legume crops are harvested, all the fruit and plant roots are removed and these lands will be tilled to grow other crops, so the input of organic matter is very limited. Agroforestry systems increase the distribution of roots in the soil and increase the recalcitrant compounds which slow the rate of mineralization through the input of organic matter (Recous et al., 2008).

4.4 Study limitations

The results of the study are based on field data collected over a relatively short period of time. Due to the complexity of field conditions, the number of soil profiles in some of the comparative studies in the sampling frame design was not entirely consistent, and future studies will need to expand the study area to achieve balanced sampling. This study examined differences in SOC at individual time points, and follow-up assessments are needed to confirm long-term trends. Factors such as soil bulk density, soil ph, root biomass, fertilizer management, and tillage practices also affect soil organic carbon in terraced areas, and more indicator measurements and studies are necessary. We need to do more work to understand the SOC characteristics of terraced agricultural areas and how to better utilize the terraces for carbon storage and realize the economic and ecological value of terraces.

5 Conclusions

The results showed that the SOC content in 0-100 cm of terraced fields planted

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with wheat was 1.5 times higher than that of sloping fields planted with wheat. Compared with sloping land, terrace construction significantly increased the SOC content of cultivated land, especially in the top soil layer (0-30 cm), and converting some sloping land into terraces would enhance the carbon sequestration capacity. Abandonment, vegetation type and planting structure affect the SOC of terraces. planting other crops between rows of apple trees can increase the SOC content. Since vegetation restoration takes a long time, short-term abandonment will lead to a decrease in terrace SOC, and some abandoned terraces can be planted with ecological restoration vegetation. Among the ecologically restored plant species, the vegetation with the highest SOC content is Pinus oleifera. The SOC content of terraces planted with artificial forage is lower than that of natural grassland, so it is necessary to protect the natural grassland left behind and choose tree species with better ecological benefits when planting trees. In the face of China's huge food pressure and the goal of increasing carbon sinks to mitigate global climate change, terraces have significance and importance. Continuous strengthening of terraces management will give full play to their carbon sequestration role.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author, soil organic carbon data are not publicly available due to privacy or ethical restrictions.

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Conflict of Interest Statement

The authors declare no conflicts of interest.

Author contributions

Guofeng Zhu and Qinqin Wang conceived the idea of the study; Siyu Lu, Xiaoyu Qi and Ling Zhao analyzed the data; Dongdong Qiu, Longhu Chen and Rui Li were responsible for field sampling; Qinqin Wang and Yuanxiao Xu participated in the experiment; Yinying Jiao, Gaojia Meng and Wenmin Li participated in the drawing; Qinqin Wang wrote the paper; Yuhao Wang, Wentong Li and Eenwei Huang checked and edited language. All authors discussed the results and revised the manuscript.

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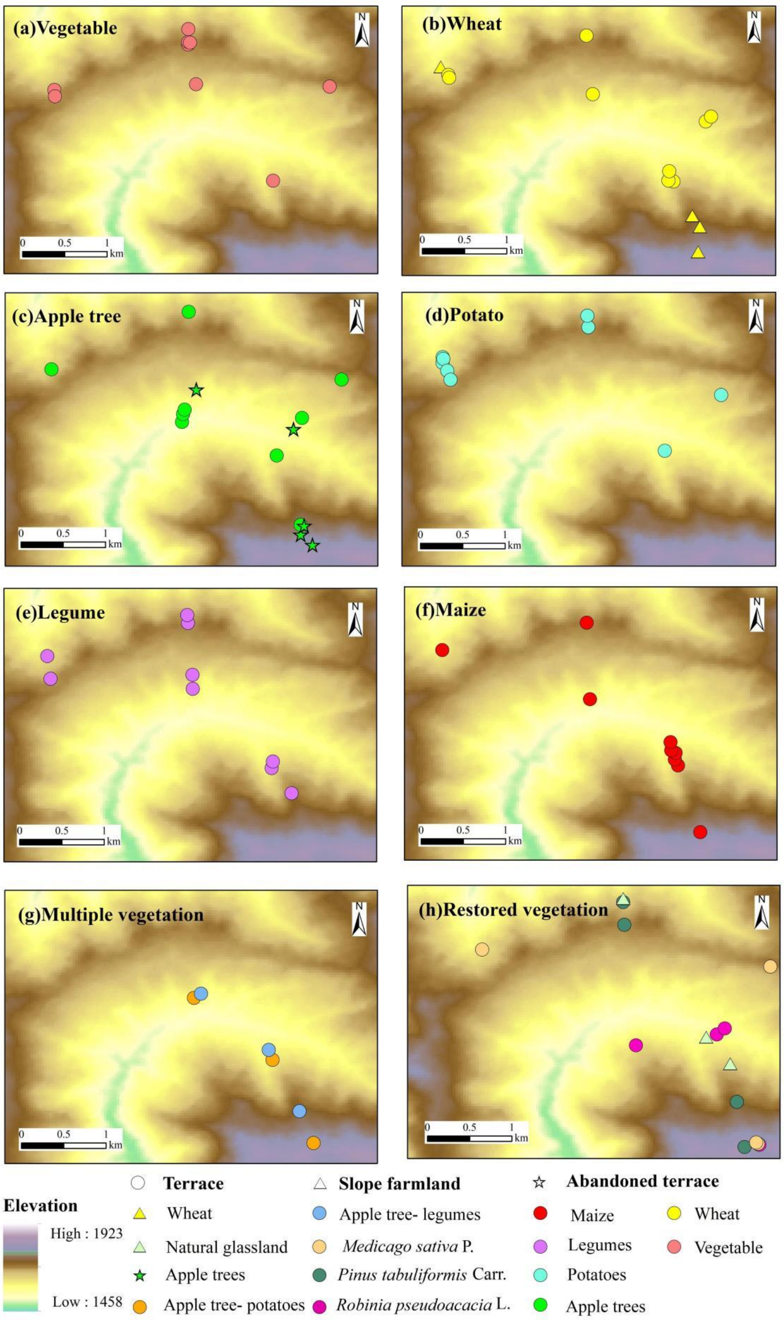
701 # Appendix



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703 Fig.A1 Detailed distribution of randomly placed sampling points in the study area. These sampling

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points cover various crop types, including apple trees, vegetable, wheat, legume, potato, maize, apple tree-legume, and apple-potato. Additionally, the figure also displays the distribution of sampling points under different planting patterns, specifically terraced sampling points, sloping land sampling points, and abandoned terraced sampling points.