Changes in Soil Carbon Fractions and Enzyme Activities Under Different Vegetation Types of the Northern Loess Plateau

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Abstract

Vegetation restoration can not only preserve soil and water and reduce soil erosion, but also improve soil properties and quality significantly. However, different vegetation types have different effects on soil organic carbon fractions and enzyme activities. In this study, we examined the response of soil organic carbon fractions and enzyme activities to different types of vegetation (i.e., Xanthoceras sorbifolia (XS), Hippophae rhamnoides (HR), Caragana korshinskii (CK), Grassland (GL)) on the northern Loess Plateau. The contents of soil organic carbon (SOC), microbial biomass carbon (MBC), easily oxidized carbon (EOC) and particulate organic carbon (POC) and the enzyme activities (i.e., amylase, catalase, urease and surase) were investigated at the end of plant growth. We found that the content of soil SOC fractions and enzyme activities upper > lower layer in each vegetation types except for MBC and catalase activity. There was no significant difference in MBC content and catalase activity between soil layers. The EOC and amylase of GL vegetation were significantly higher than other vegetation types. POC, SOC, urease and sucrase were significantly higher in SX vegetation than other vegetation types. The maximum soil MBC content was found in HR vegetation, and among the four vegetation types, the MBC content showed significant differences in lower layer, but no significant difference in the surface soil. Correlation analysis showed that the MBC significant influenced on the catalase activities; POC significant affected urease and sucrase activities; SOC extremely significant influenced on the urease and sucrase activities. Therefore, vegetation type was an important factor affecting the change of soil enzyme activities and carbon fractions on the Loess Plateau.

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Abstract: Vegetation restoration can not only preserve soil and water and reduce soil erosion, but also improve soil properties and quality significantly. However, different vegetation types have different effects on soil organic carbon fractions and enzyme activities. In this study, we examined the response of soil organic carbon fractions and enzyme activities to different types of vegetation (i.e., *Xanthoceras sorbifolia* (XS), *Hippophae rhamnoides* (HR), *Caragana korshinskii* (CK), Grassland (GL)) on the northern Loess Plateau. The contents of soil organic carbon (SOC), microbial biomass carbon (MBC), easily oxidized carbon (EOC) and particulate organic carbon (POC) and the enzyme activities (i.e., amylase, catalase, urease and surase) were investigated at the end of plant growth. We found that the content of soil SOC fractions and enzyme activities upper > lower layer in each vegetation types except for MBC and catalase activity. There was no significant difference in MBC content and catalase activity between soil layers. The EOC and amylase of

GL vegetation were significantly higher than other vegetation types. POC, SOC, urease and sucrase were significantly higher in SX vegetation than other vegetation types. The maximum soil MBC content was found in HR vegetation, and among the four vegetation types, the MBC content showed significant differences in lower layer, but no significant difference in the surface soil. Correlation analysis showed that the MBC significant influenced on the catalase activities; POC significant affected urease and sucrase activities; SOC extremely significant influenced on the urease and sucrase activities. Therefore, vegetation type was an important factor affecting the change of soil enzyme activities and carbon fractions on the Loess Plateau.

Keywords: Vegetation types; Soil organic carbon components; Enzyme Activities; Loess Plateau

1. Introduction

Soil organic carbon (SOC) is a sensitive indicator of climate change, which can be used to indicate the response of soil to climate change (Don, Schumacher, & Freibauer, 2011), and also play important roles in the carbon cycle (Eclesia, Jobbagy, Jackson, Rizzotto, & Piñeiro, 2016). However, the SOC pool consists of sub-pools with different turnover rates, which have different sensitivity to environmental changes (Guo, Wang, Wang, Wu, & Cao, 2018). Therefore, in order to estimate the response of the SOC to environmental change more accurately, we need to separate the SOC into different fractions. Soil active organic carbon mainly includes microbial biomass carbon (MBC), easily oxidized carbon (EOC) and particulate organic carbon (POC). Although the proportion of soil active organic carbon to soil total organic carbon is low, it can reflect the changes of soil carbon pool caused by soil management measures and environmental changes (Jha et al., 2012; Sahoo, Singh, Gogoi, Kenye, & Sahoo, 2019). The soil active organic carbon can be directly involved in the soil biological chemical conversion process (Sun et al., 2014), plays an important role in the soil nutrient cycling, and is the storage of soil nutrients (Simard, Fyles, D, & Nguyen, 2001). Furthermore, soil active organic carbon is easily and strongly affected by plants and microorganisms (Chen, Zhou, & Xiao, 2010; Kimura, Murase, & Lu, 2004). However, knowledge concerning the variation of soil active organic carbon content under different vegetation types is poor.

Soil enzyme activities participate in the biochemical processes of the soil system and are the key link to the "plant-soil enzymes-soil nutrients" (Araújo et al., 2013; da Silva et al., 2012; Lino et al., 2015; Nannipieri et al., 2012). In particularly, the activities of soil carbon cycle-related enzymes (i.e., amylase, catalase, urease and sucrase), as important indicators of soil fertility, play crucial roles in the soil organic matter circulation and energy transformation of the soil ecosystem (Bergstrom et al., 1999; Burns et al., 2013). The enzyme activities rapidly change if the soil nutrient status is altered (Ciarkowska, Solek-Podwika, & Wieczorek, 2014). Plants can influence soil enzyme activities by excreting exogenous enzymes, and affect microbial species composition and diversity by releasing exudates and oxygen into the rhizosphere that in turn indirectly affect enzyme activity (Singh & Kumar, 2008). Plants can also indirectly mediate enzyme activities in soil through controlling aboveground litter quantity (Caravaca, Alguacil, Torres, & Roldán, 2005). Therefore, these enzyme activities were often chosen to understand the variations in SOC and soil quality (Acosta-Martínez, Cruz, Sotomayor-Ramírez, & Pérez-Alegría, 2007; Chen et al., 2016).

The Loess Plateau is located in the north-central part of China. It is one of the most concentrated and largest loess areas on the earth, with a total area of 64,000 square kilometers. At the same time, it is also one of the areas with the most serious soil erosion and the most fragile ecological environment in the world, thus vegetation in this area is so important to enhances soil water holding capacity and fertility levels (García, Hernández, & Costa, 1994). Over the past few decades, extensive environmental restoration have been implemented to improve the fragile natural ecosystems on the Loess Plateau (Intergovernmental Panel on Climate Change, 2014). Vegetation restoration can not only preserve soil and water and reduce soil erosion (Ran, Lu, & Xu, 2013), but also improve soil properties and quality significantly (Zhang et al., 2019). Future climate change may have a complex impact on the soil enzyme system in terrestrial ecosystems, thus affecting the relevant soil SOC, nutrient processes. Sucrase supply energy for crop roots and microorganisms growth (Hu et al., 2014; Kang, Liu, Wan, & Wang, 2011). However, there is a lack of information on the relationship between soil carbon fractions and enzyme activities in different vegetation types. The goal of our study was to evaluate the effect of vegetation types on soil carbon fractions and enzyme activities in 40-cm soil layers on

the Loess Plateau. We hypothesized that both carbon fraction contents and enzyme activities of woodland in the same soil layer are higher than that of bushes and grassland, carbon fraction contents and enzyme activities under all vegetation soils are higher in the surface layer than in the underlying layer.

2. Materials and methods

2.1. Site description

The study area (103°52'-105deg13' E, 34deg26'-35deg35' N) is located in the middle of Gansu Province in northwest China (Fig. 1) and possesses the hills and gullies typical of the middle of the Loess Plateau. Its average elevation is about 1947 m. It has a semi-arid climate and average annual precipitation of about 390.99 mm, which falls mostly from July to September following the harvest season. The soil is a typical loess soil, which is soft and prone to erosion. In recent decades, large-scale vegetation restoration was implemented by the government to address ecological degradation. As such, a large area of sloped cropland was replanted with trees and shrubs. The major tree species planted during each period of reforestation are *Xanthoceras sorbifolia* ,*Caragana korshinskii,* and *Hippophae rhamnoides* .

2.2. Experimental design and soil sampling

In the experimental site, the grassland (GL; Area: 30 m x 40 m; 35deg34'54"N, 104deg37'57"E) was the control group, while *Xanthoceras sorbifolia* (XS; Area: 20 m x 50 m; 35deg35'10"N, 104deg37'7"E),*Caragana korshinskii* (CK; Area: 30 m x 30 m; 35deg34'55"N, 104deg38'1"E), and *Hippophae rhamnoides* (HR; Area: 20 m x 30 m; 35deg34'45"N, 104deg39'1"E) were designated as the three vegetation types (Table 1). Three sample plots (with the size of 8 m x 8 m) were randomly selected form each vegetation type for sampling.

In September 2017, the soil sampler (diameter 5 cm) was used to sample layers (0-20, 20-40cm) according to the diagonal 5-point method (four points were selected at both ends of an "X", with one point selected at the intersection). Five soil samples of the same soil layer in each plot were mixed to form one soil sample for a total of 24 soil samples. After removing debris, such as soil samples and residual roots, the sample was divided into two parts. One part of the fresh soil was stored in a refrigerator at 4 degC through a 2mm soil sieve. Another part of the soil was air-dried (direct sunlight was avoided on soil samples), placed in a ziplock bag through a 100-mesh soil sieve, and stored in a cool and ventilated place (storage time not exceeding one year).

2.3. Soil carbon fractions

SOC was determined by the Walkley-Black dichromate oxidation method(Nelson, 1982), using a mixture of potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid (H_2SO_4) to oxidize the organic matter, after which it was titrated against ferrous sulfate ($FeSO_4$). The air-dried soil sample (0.1g) was extracted with 7.5 ml of $K_2Cr_2O_7$and 7.5 ml of concentrated H_2SO_4 at 180 degC for 30 min.

MBC was determined on fresh soil samples (sieving < 2 mm) using the chloroform fumigation-extraction method(Vance, Brookes, & Jenkinson, 1987). The fumigated and non-fumigated soil (5g, accurate to 0.001g) were extracted with 20 ml 0.5 M of K_2SO_4 for 30 min on a shaker (180 r/min). 5 ml of supernatant was extracted and titrated according to the method of organic carbon. MBC was calculated as (C fumigated-C non-fumigated)/0.38(McLatchey & Reddy, 1998).

POC was determined with necessary modifications based on the method described by Yang(Yang et al., 2009). Twenty grams of the soil were dispersed with 100 mL of a 5 g/L sodium hexametaphosphate solution by hand shaking the mixture for 15 min and placing it on a reciprocal shaker (100 r/min) for 16 h. The dispersed soil sample was then passed through a 53 μm sieve and rinsed thoroughly with distilled water. The remaining material was dried at 50°C, weighed and finely ground.

EOC was measured by slightly modifying the light group organic compound separation method using $KMnO_4$ oxidation(Janzen et al.,1992).

2.4. Soil enzymes activities

Soil catalase activity was determined using the potassium permanganate titration(Guan,1986; Li et al, 2014). 40 ml of distilled water and 5 ml of hydrogen peroxide solution (3%) were added to 2 g of soil, which was shaken for 30 min and then filtered. We then took 25ml of the filtrate and titrated it to pink with 0.1 M potassium permanganate.

The urease activities were analyzed according to the methods used by Guan and Yin(Guan,1986; Yin et al, 2014). The soil (2 g) was treated with 10 ml urea (10%), 20 ml citrate buffer (1 M, pH 6.7), and 1 ml of methylbenzene and stored at room temperature for 15 min. The sample was then shaken at 37 for 24 h. The solution was filtered, and 1 ml of the filtrate was mixed with 20 ml of distilled water, 4 ml of sodium phenolate hydroxide, and 3.0 ml of sodium hypochlorite. The NH_4^+-N was analyzed 20 minutes later using a Spectrophotometer at 578 nm. Urease activity was expressed in milligrams of NH_4^+-N per gram of dry soil released in 24 h.

The invertase activity and amylase enzyme activities were analyzed according to the methods used by Guan(Guan, 1986). using 3, 5-dinitrosalicylic acid, the invertase activity and amylase activities were measured using sucrose solution and soluble starch as respective substrates, respectively. The invertase activity was expressed as the mass (mg) of glucose in 1 g of soil after 24 h; the amylase activity was expressed as the mass (mg) of maltose in 1 g of soil after 24 h.

2.5. Statistical analysis

We used the Turky-Kramer method to analyze significant differences in the soil carbon component content and enzyme activity under different vegetation types. A two-way ANOVA test was used to analyze the effects of vegetation type and soil layer depth on the soil organic carbon components and enzyme activities. The confidence interval was 95%, and $P < 0.05$ was considered significant. The errors in the figures and tables of this article are standard errors. The relationship between soil catalase, sucrase, amylase, urease and soil carbon fractions were analyzed using a Pearson correlation analysis.

3. Results

3.1. Variation of soil physical and chemical properties in different vegetation types

The type of vegetation had significant effects on the soil's basic physical and chemical properties. The bulk density of the 0-20 cm CK soil layer was significantly lower than both in both HR and GL (Table 2).

The contents of total nitrogen and total phosphorus in the XS 0-20 cm layer were significantly higher than those in the other three vegetation types ($P < 0.05$). The soil bulk density of the 20-40 cm layer under all four vegetation types was higher than that in the 0-20 cm layer, while the total porosity, total nitrogen and total phosphorus in the 20-40 cm soil layer were lower than in the 0-20 cm layer.

3.2. Variation of soil carbon fractions in different vegetation types

There were significant differences in EOC, POC, and SOC under the four types of vegetation (Figure 2).

There were no significant differences in the soil MBC content among the four types of vegetation in the 0-20 cm layer. The MBC content in the 20-40 cm layer of HR vegetation was significantly higher than in the other three vegetation types. Except for the MBC contents of the HR vegetation, the MBC, EOC, POC, and SOC contents in other vegetation types decreased significantly as soil depth increased. At the 0-20 cm layer, the EOC contents of the GL vegetation was 1.44, 2.82, and 2.06 g/kg higher than XS, HR, and CK, respectively, while at the 20-40 cm layer the EOC contents was 0.63, 1.01, and 0.95 g/kg higher than XS, HR, and CK, respectively. The POC and SOC contents in the 0-20 cm layer of XS vegetation were significantly higher than those in the other three vegetation types. The soil POC content in HR vegetation and the SOC content in GL vegetation at the 20-40 cm layer were the highest. The maximum values of soil POC and SOC were 0.37 and 1.61 g/kg higher than the minimum values, respectively. A two-way ANOVA analysis demonstrated significant associations between soil depth and vegetation type on organic carbon components (MBC, EOC, POC and SOC) in all the samples measured (Table 3).

3.3. Variation of soil enzyme activities in different vegetation types

The type of vegetation significantly affected soil amylase, urease, and sucrase activities (Figure 3).

There were no significant differences in soil catalase activity among the four vegetation types. However, a two-way ANOVA test revealed a significant association between soil depth and vegetation type on catalase activity (Table 3). For the 0-20cm soil layer, the amylase activity in GL vegetation was significantly higher than that of the other three vegetation types (Figure 3A); the urease activity of XS vegetation was significantly higher than that of HR, CK, and GL by 58.75, 69.04, and 48.49 mg/g, respectively (Figure 3C); soil sucrase activity in GL vegetation was significantly higher than HR and CK by 110.23 and 423.35 mg/g, respectively, but no significant difference was observed in XS vegetation (Figure 3D). In the 20-40cm soil layer, HR amylase activity displayed significant differences with CK, and displayed no significant differences with XS and GL. The CK amylase activity was significantly lower than the other three vegetation types. The soil urease activity in the 20-40 cm layer of XS vegetation was significantly higher than that of the other three types of vegetation. As soil depth increased, vegetation soil catalase and sucrase activities increased (except for CK). Soil enzyme activity under other vegetation types was greater in the upper layers than in the lower layers. A two-way ANOVA test demonstrated extremely significant relationships between soil depth and vegetation type on enzyme activity (amylase, urease, sucrase) in all samples studied (Table 3).

3.4. Relationships among the SOC fractions, enzyme activities, physical and chemical characteristics

A correlation analysis (Table 4) demonstrated that the MBC content displayed an extremely significant positive correlation with the POC and catalase and displayed an extremely significant negative correlation with EOC (with a correlation coefficient was 0.911). The POC was significantly correlated with the SOC, urease, sucrase, total N and P, however, no significant correlations were observed with amylase, catalase, total porosity, and bulk density. The SOC was significantly correlated with urease, sucrase, total N, total P, total porosity, and bulk density. Soil sucrase activity displayed an extremely significant correlaion with amylase and urease,with respective correlation coefficients of 0.597 and 0.848. Physical and chemical characteristics of the soil (i.e., total N, total P, total porosity, and bulk density) displayed strong positive correlation with urease and surase.

4. Discussion

4.1. Soil carbon fraction of different type vegetations

Vegetation is one of the most important components of an ecosystem, and its community succession has a significant effect on the SOC content (Deng et al., 2018; Solomon et al., 2007). This study demonstrated that SOC content in a forest was significantly higher than in shrublands and grasslands (Figure 2D). Root exudates and litter from forest vegetation both strongly affected the organic carbon content in the soil and promoted the effectiveness of forest nutrients(Qiao, Miao, Silva, & Horwath, 2014). At the same time, forest vegetation can also alter the forest environment, reducing solar radiation and temperature differences, increasing soil moisture(Ozkan & Gokbulak, 2017), and creating a stable environment for litter decomposition. All of this causes the soil organic carbon content of forest to be higher than that of shrublands and grasslands. Moreover, due to the higher coverage of herbaceous vegetation and abundant species density (Table 1), more surface litter increases the sources of organic carbon (Zhang et al., 2019), making the SOC content of desert grassland vegetation higher than that of both HR and CK vegetation. Meanwhile, the SOC content of the four vegetation types was not only due to organic C inputs, but was also affected by physical and chemical characteristics and enzyme activities of the soil. A correlation analysis between SOC contents and soil physical and chemical characteristics and enzyme activities further confirmed these results (Table 4).

The MBC content in the soil of HR was significantly higher than in the soil of GL (Figure 2A). On the one hand, HR vegetation has a wide horizontal root structure and can quickly grow new shoots(Letchamo et al., 2018). These new shoots increase soil porosity (Table 2) and oxygen content during the growth process, and increased soil aerobic microbial activity. On the other hand, the root nodules of *Hippophae rhamnoides*

can fix atmospheric nitrogen and improve soil fertility (their annual average nitrogen accumulation is 17,475 kg/hm^2)(Ruan & Li, 2002). Studies have shown that increasing soil nitrogen can promote microbial activity and increase the decomposition rate of soil organic matter(Nottingham et al., 2012; Sistla, Asao, & Schimel, 2012), thereby reducing soil organic carbon content. The partial shading effect of XS vegetation reduces the soil temperature and the activity of soil microorganisms (Jimenez, Tejedor, & Rodriguez, 2007). Therefore, the soil MBC content is highest in HR vegetation.

The changes in soil POC and SOC are consistent (Figure 2C) across different types of vegetation, while the changes in EOC and SOC differ (Figure 2B). Since the soil in this study was obtained from different types of vegetation, different physical and chemical properties (Table 2) regulate the decomposition rates in the soil (Xu et al., 2016). Various surface litter can significantly change the input of soil organic matter(Thorburn, Meier, Collins, & Robertson, 2012), which affects the EOC content in the surface soil (DuPont, Culman, Ferris, Buckley, & Glover, 2010). At the same time, the higher soil temperature and the lower soil water content, which may potentially create more beneficial conditions to enhance labile C fractions(Chen et al., 2016). However, the decomposition of plant litter is the most complex ecological process in the biosphere(Mendez, Martinez, Araujo, & Austin, 2019). Therefore, the soil active carbon fractions may be affected by the physical and chemical properties of the soil, various environmental factors, and the activity of microorganisms.

The content of activated carbon in the soil under the four vegetation types was greater in the upper layer than in the lower layer. This was mainly because the soil active organic carbon largely depends on the total organic carbon content of the soil. Total organic carbon decreased as soil depth increased (Figure 2D), however, the litter on the upper layer not only provides a significant amount of organic carbon for the soil, but also provides the surface soil with a high concentration of nutrients (Table 2), providing stable conditions for growing fine roots in the topsoil layer. Litter and root exudates have become an important source of soil active organic carbon after they are decomposed by microorganisms(Weintraub, Scott-Denton, Schmidt, & Monson, 2007).

4.2. Soil enzyme activity of different type vegetations

Our study shows that different vegetation types affect soil enzyme activity differently (Figure 3). Urease, a key enzyme that regulates soil nitrogen transformation, comes mainly from plants and microbes and plays a key role in nutrient cycling(Zhao, Li, & Wang, 2012). Soil urease activity in XS vegetation is higher than in the others (Figure 2C). The high urease activities in XS vegetation may be due to both microbial growth and stimulation of microbial activity by enhanced resource availability(Li et al., 2014). At the same time, higher soil nutrients (Table 2) and SOC contents (Figure 2D) provide microorganisms with a rich source of nitrogen and carbon, which significantly adds to the nutrients accumulated by transformation (Cui et al., 2019). Improving the physical properties of soil creates an environment that benefits microorganisms(Iovieno, Morra, Leone, Pagano, & Alfani, 2009) and increases urease activity.

We found that the different vegetation types do not significantly affect soil catalase activity, which could be related to the metabolic activity of aerobic organisms(Brzezińska, Włodarczyk, Stepniewski, & Przywara, 2005). It can decompose hydrogen peroxide into molecular oxygen and water to prevent cells from damage by reactive oxygen species (Bartkowiak & Lemanowicz, 2017). As such, we observed no significant change in catalase activity in adverse environments.

Soil amylase and cellulose enzymes are responsible for the rate and course of plant material decomposition and plant debris degradation(Piotrowska, 2014).Significant differences in soil amylase and sucrase activities were observed under the four vegetation types ($P < 0.05$). The activities of amylase (Figure 3A) and sucrase (Figure 3D) in GL vegetation in the 0-20 cm layer were significantly higher than in the other three vegetation types. In the 20-40 cm layer, the soil amylase activity in the HR vegetation was the highest, while there was no significant difference in the other three vegetation types. The soil sucrase in the XS vegetation was significantly higher than that in the other three vegetation types. Because there are more types of vegetation and litter on the surface of GL, the content of SOC fractions is higher (Figure 2), and soil organic matter has a higher input capacity, which affects the community structure and growth of rhizosphere soil

microorganisms (Prescott, 2010). GL vegetation is also dominated by low, herbaceous vegetation (Table 1). The shade effect of this vegetation is small, and soil temperature is higher than in the other three vegetation types, resulting in higher soil amylase and invertase activities in GL vegetation. The higher MBC, POC contents (Figure 2A, C), and total porosity (Table 2) in the 20-40 cm layer of HR vegetation provide a source of oxygen for microbial activity, while the root system of GL vegetation is mainly concentrated in the 0-20 cm layer, meaning that amylase in HR vegetation is more active in the 20-40 cm layer.

In all four vegetation types, the soil amylase, urease, and sucrase activities were greater in the upper layer than in the lower layer, while the soil catalase activity did not change significantly. Due to the high SOC content (Figure 2), there are sufficient nutrient sources to facilitate the growth of microorganisms. In addition, higher surface temperatures and better ventilation enable soil microorganisms to quickly grow and metabolize(Chen, Shang, Cai, & Zhu, 2019). The underground biomass in the 20-40 cm soil layer was reduced, which reduces the source of soil nutrients, while this reduction of SOC content and plant roots often leads to a decrease in enzyme activity (Xiao, Huang, & Lu, 2015). The effects of vegetation on soil enzyme activities (i.e., amylase, catalase, urease and sucrase) are different under different soil types and environmental conditions.

4.3. Relationship between soil carbon fraction and enzyme activity

Enzymes participate in the transformation process of soil nutrients. Enzyme activity plays a vital role in soil microbial activity and soil quality(Ebhin Masto, Chhonkar, Singh, & Patra, 2006). Under stable organic nutrient conditions soil enzyme activity is typically higher, and increased mineralization of the soil's nutrients creates a more favorable environment for nutrient cycling (Roldán, Salinas-García, Alguacil, & Caravaca, 2005). The results of this study demonstrate that catalase activity was significantly related to MBC content, and can reflect the changing process of MBC. Both urease activity and invertase activity displayed significant positive correlations with organic carbon and total nitrogen content. Urease and invertase activity can reflect the decomposition of organic matter and nitrogen in soil and can be used as important indicators of soil fertility. In sum, enzyme activity and carbon fraction influence each other's conversion and circulation of nutrients(Qi et al., 2016; S. Zhao et al., 2016).

5. Conclusions

This study analyzed the responses of soil organic carbon fractions and related enzyme activities to different vegetation types in the northern Loess Plateau. Our results demonstrated that the content of soil SOC, EOC and POC were greater in the upper layer than in the lower layer in each type of vegetation, except for MBC. Vegetation types effected on soil organic carbon fractions differently. The maximum MBC content in the upper soil was observed in HR vegetation, the maximum EOC content was observed in GL vegetation, and the soil POC and SOC contents of SX vegetation were significantly higher than in the other three vegetation types. Moreover, the type of vegetation significantly influenced soil enzyme activities, except for catalase. For all four vegetation types, the soil amylase, urease, and sucrase were all significantly higher in the upper than in the lower layer. In contrast, the soil catalase displayed no significant difference between soil layers. Correlation analysis showed that the MBC has a significant effect on catalase activities, that POC significantly affected urease and sucrase activities, and that SOC displayed an extremely significant effect on urease and sucrase activities. Lastly, vegetation types and hydrological conditions could have profound effects on the soil organic carbon fractions and enzyme activities. In conclusion, the type of vegetation was an important factor influencing the kind of soil enzyme activity and carbon fractions on the Loess Plateau. As such, more long-term studies are needed to better understand the mechanism of SOC dynamics across the different types of vegetation on the Loess Plateau.

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Conflicts of Interest

The authors declare no conflict of interest.

Author contributions

Jiangqi Wu: experiments (design). Jiangqi Wu and Haiyan Wang: experiments (perform) and data collection. Jiangqi Wu: data analysis. Jiangqi Wu, Haiyan Wang, Guang Li and Lijuan Yan: paper writing.

Data accessibility statement

The soil organic carbon fractions and enzyme activities data in Dryad:*https://doi.org/10.5061/*

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Table 1. The basic information of different vegetation types

Vegetation	Main species	Coverage/%	Plants height /m
XS	*Xanthoceras sorbifolia*, *Agropyron cristatum (Linn.) Gaertn, Bupleurum chinense*)	60	6
HR	*Hippophae rhamnoides*, *Medicago sativa*, *Agropyron cristatum (Linn.) Gaertn*	85	0.6
CK	*Caragana korshinskii*, *Agropyron cristatum (Linn.) Gaertn*	30	1
GL	*Agropyron cristatum (Linn.) Gaertn, Artemisia frigida Willd.Sp.Pl.*, *Stipa grandis P.Smirn.*	>90	0.2

Table 2. Basic properties of the soils for the four vegetation types.

Vegetation	soil layers (cm)	Bulk density (g/cm^3)	Total porosity (%)	Total N (g/kg)	Total P (mg/kg
XS	0-20	1.54 ± 0.02 AB	67.38 ± 1.67 A	**0.66 ± 0.00 A**	**43.15 ± 0.75 A**
	20-40	1.66 ± 0.02 A	56.17 ± 1.10 BC	0.33 ± 0.00 A	30.56 ± 0.97 B
HR	0-20	1.58 ± 0.02 A	62.46 ± 0.61 A	0.43 ± 0.00 B	42.13 ± 0.49 A
	20-40	1.65 ± 0.06 A	**66.41 ± 1.65 A**	0.37 ± 0.04 A	32.32 ± 1.00 AB
CK	0-20	1.50 ± 0.03 B	67.33 ± 1.01 A	0.39 ± 0.00 C	33.76 ± 0.12 C
	20-40	1.56 ± 0.08 A	63.00 ± 3.31 AB	0.31 ± 0.00 A	32.45 ± 0.36 AB
GL	0-20	**1.59 ± 0.02 A**	67.06 ± 2.43 A	0.40 ± 0.01 C	37.44 ± 0.48 B
	20-40	**1.71 ± 0.02 A**	54.59 ± 2.31 C	0.33 ± 0.01 A	**34.63 ± 0.13 A**

Note: Capital letters indicate that there are significant differences ($P < 0.05$) between vegetation types under the same soil layer ($n = 12$). The error is the standard error.

Table 3. Two-factor ANOVA analysis was used to test the differences in soil organic carbon components (MBC, EOC, POC, SOC) and enzyme activities (amylase, catalase, urease, and invertase). VT: vegetation type, SD: soil depth.

	MBC	MBC	MBC	EOC	EOC	EOC	POC	POC	POC	S
	df	F	P	df	F	P	df	F	P	df
VT	3	33.210	.000	3	298.827	.000	3	17.438	.000	3

	MBC	MBC	MBC	EOC	EOC	EOC	POC	POC	POC	S
SD	1	65.499	.000	1	2320.578	.000	1	449.429	.000	1
VT × SD	3	15.946	.000	3	61.852	.000	3	37.881	.000	3
	Amylase	**Amylase**	**Amylase**	**Catalase**	**Catalase**	**Catalase**	**Urease**	**Urease**	**Urease**	**S**
	df	F	P	df	F	P	df	F	P	df
VT	3	13.920	.000	3	1.260	.321	3	1964.539	.000	3
SD	1	93.711	.000	1	0.222	.644	1	10051.341	.000	1
VT × SD	3	7.227	.003	3	4.398	.019	3	712.897	.000	3

Table 4. The correlation coefficients between soil labile organic carbon and enzyme activities

Correlation coefficients	**MBC**	**EOC**	**POC**	**SOC**	**Amylase**	**Catalase**	**Urease**	**Sucrase**	**Total N**	**T**
MBC	1	-.911**	.596*	-.136	.206	.694*	-.197	-.154	-.117	-
EOC		1	-.378	.459	-.254	-.485	.487	.347	.423	.
POC			1	.591*	.492	.518	.582*	.629*	.629*	.
SOC				1	.069	.317	.984**	.767**	.990**	.
Amylase					1	-.258	.198	.597*	.130	.
Catalase						1	.197	-.145	.320	.
Urease							1	.848**	.980**	.
Surase								1	.776**	.
Total N									1	.
Total P										1
Total porosity										
Bulk density										

Note: **. Significant relation at 0.01 levels = * .Significant relation at 0.05 levels

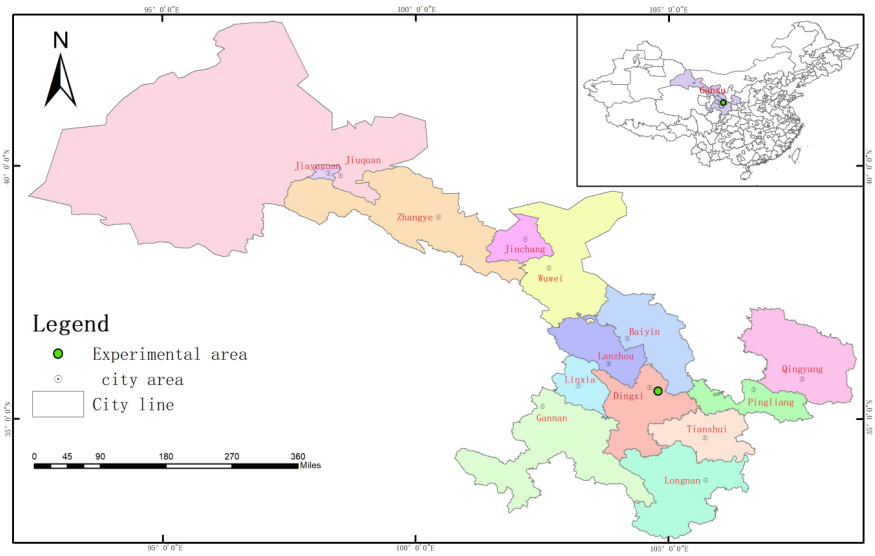

Figure 1. The geographical location map of the study area.

Figure 2. MBC (A), EOC (B), POC (C) and SOC (D) under different vegetation types.

Note: Capital letters indicate significant differences ($P < 0.05$) between vegetation types. The error bar is the standard error.

Figure 3. Soil amylase (A), catalase (B), urease (C) and sucrase (D) activity under different vegetation types.

Note: Capital letters indicate significant differences ($P < 0.05$) between vegetation types. The error bar is the standard error.

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