

# The response of soil organic carbon to climate and soil texture in China

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**Abstract** Soil organic carbon (SOC) plays an essential role in the carbon cycle and global warming mitigation, and it varies spatially in relation to other soil and environmental properties. But the national distributions and the impact mechanisms of SOC remain debated in China. Therefore, how soil texture and climate factors affect the SOC content and the regional differences in SOC content were explored by analyzing 7857 surface soil samples with different land-use. The results showed that the SOC content in China, with a mean value of  $11.20 \text{ g} \cdot \text{kg}^{-1}$ , increased gradually from north to south. The SOC content of arable land in each geographical area was lower than in grassland and forest-land. Although temperature also played a specific role in the SOC content, precipitation was the most critical climate factor. The SOC content was positively correlated with the silt and clay content. The lower the temperature, the greater the effect of environmental factors on SOC. In contrast, the higher the temperature, the more significant impact of soil texture on SOC. The regional difference in SOC highlights the importance of soil responses to climate change. Temperature and soil texture should be explicitly considered when predicting potential future carbon cycle and sequestration.

**Keywords** soil organic carbon, climate, soil texture, land use

## 1 Introduction

The Paris Agreement represents the general direction of the global green and low-carbon transformation. During the

General Debate of the 75th session of the General Assembly of the United Nations, Xi Jinping, President of the People's Republic of China, said that 'China will increase its nationally determined contributions, adopt more effective policies and measures, and strive to reach the peak of CO<sub>2</sub> emissions by 2030 and achieve carbon neutrality by 2060'. With this national and global advocacy, the research of regional carbon distribution and reserves are becoming increasingly crucial.

Terrestrial soil stores large amounts of carbon (C) and constitutes one of the primary atmospheric C pools (Li et al., 2014). Small changes in the soil organic carbon (SOC) pool affect the nutrient supply of terrestrial vegetation, which in turn has a profound effect on the distribution, composition, structure and function of terrestrial ecosystems (Xu et al., 2019; Liao et al., 2020). SOC stocks are generally controlled by C inputs, including residues, secretion and exudates of plant, animal and microbial (Sasmito et al., 2020), and C outputs, such as mineralization, soil erosion and export (Robinson et al., 2020). Therefore, SOC plays a vital role in C cycling and mitigating global warming (Zhang et al., 2019).

Climate, soil texture, and land use changes are critical factors in regulating SOC and are standard model inputs that simulate SOC dynamics to estimate and predict SOC reserves (Smith and Waring, 2019; Pathak and Reddy, 2021; Riggers et al., 2021). In a regional context, several studies have presented different insights. Kang et al. (2020) reported that SOC increases with an increase in temperature and precipitation. The major climatic factors (temperature or precipitation) may exhibit regional differences. Soil organic matter can increase chemical stability and provide physical protection against microbial decomposition by aggregating or tightly binding with clay particles (Six et al., 2002). The SOC content is generally believed to be directly proportional to the clay and powder

content, but inversely proportional to the sand content (Xiao et al., 2020; Zhang et al., 2020). Overall, the relationship between climate or soil texture and SOC is characterized by regional differences that explain variability.

Land use/cover change has a significant impact on SOC, with agricultural activities, deforestation, and returning farmland to forest being particularly important (Shi et al., 2015). Since 2000, the ‘Grain for Green’ project initiated by the Chinese Government was implemented. Almost 18% of the total country area has been successfully converted into forest land (Yan, 2019). Vegetation restoration affects the input and output of organic matter, and therefore affects the SOC content (Fang et al., 2014). Researchers have found that the surface SOC in an agricultural system is lower than that in adjacent original forest soil because the farmland ecosystem exports a large amount of organic C, leading to a low SOC input (Gao et al., 2017). The SOC sequestration enhanced over the restoration, but the SOC stability become lower, so that the recovery to the level of natural forest may meet difficulties (Xu et al., 2020). Recent studies have been conducted on SOC characteristics (Zhang et al., 2019), estimation (Zhao et al., 2017), the influences of revegetation (Chang et al., 2019) and C cycling (Zhang et al., 2020) in different regions of China. However, previous studies have been conducted over small spatial scales and short time scales. This study investigated the spatial changes of SOC content at a large spatial scale and its relationship with the corresponding environmental and texture factors. The aim of the study was to determine how soil texture and climate

factors affect SOC content and to further determine the regional differences that affect SOC content. Our study provides a theoretical basis for estimating the response of soil C pools to climate change and calibrating regional C process models.

## 2 Materials and methods

### 2.1 The study area

China is located in eastern Asia and lies along the west coast of the Pacific Ocean. The terrain is high in the west and low in the east, with a ladder distribution. The percentage breakdown of the topography across the total land area of the country is approximately 33% mountainous area, 26% plateaus, 19% basins, 12% plains, and 10% hills. The climate is complex and diverse. From north to south, there are temperate monsoon climate, subtropical monsoon climate, and tropical monsoon climate zones. The vast inland area of the north-west has a temperate continental climate. The Qinghai-Tibet Plateau is part of an alpine plateau. The monsoon area is large, with the monsoon climate being significant due to the sea and land factors. The national average precipitation is about 630 mm, which decreases from coastal to inland areas and from the southeast to northwest. In terms of provincial administrative divisions, there are four municipalities directly under the central government, 23 provinces, five autonomous regions, and two special administrative regions. The land use is mainly grassland (32.6%), arable

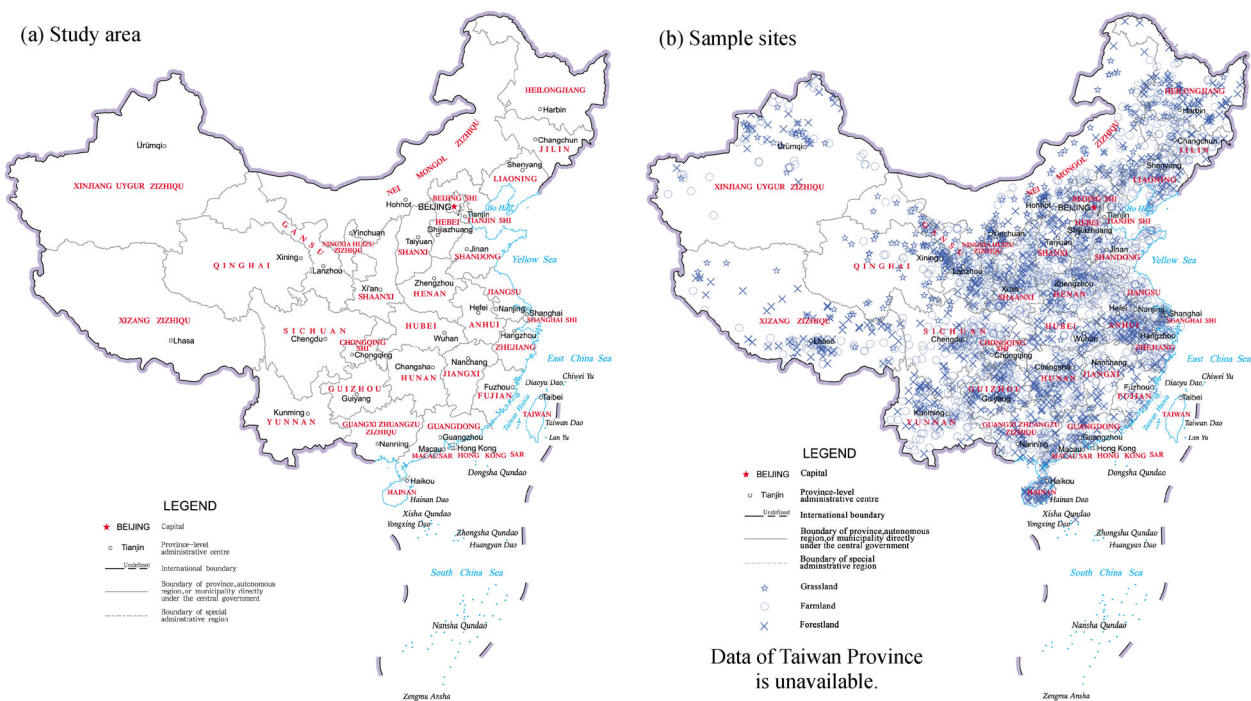


Fig. 1 Overview of the research area.

land (13.5%), and forest land (16.6%). The cultivated agricultural area in China is important for national food production.

China has a vast territory and straddles five climatic zones, resulting in an uneven distribution of SOC. To better understand the factors controlling the distribution of SOC in China, the country was divided into four natural geographical areas (northwest region, northern region, southern region, Qinghai-Tibet region). The regions were basically divided by climate. The northern region is the north of monsoon climate zone in China, which is also the north of 0°C isotherm in January and 800 mm equipluve. The southern region in China is divided by the similar basis. The northwest region is the non-monsoon climate zone and the west of 400 mm equipluve. As for the Qinghai-Tibet region, it was a unique geographical unit which has high altitude and cold weather (He and Wang, 2013).

## 2.2 Data source and processing

Chinese soil data are derived from the Chinese soil database, which is from the China's second soil survey (1980–1996), established by the CERN soil branch center of the Nanjing Institute of Soil Research, Chinese Academy of Sciences (available at Soil Science Database website). Through the collation of national data, a total of 7857 surface soil samples were accessed. There were eight soil parameters measured for each sampling point (elevation, annual mean temperature, annual average precipitation, SOC content, soil texture, total nitrogen content, total phosphorus content, and pH). The sample sites were divided into arable land (5399 samples), forest land (1584 samples), or grassland (874 samples) (Fig. 1(b)) according to the first-level classification of the Land Use Status Classification (GB/T241010-2017) issued by the Ministry of Land and Resources of China. The number of sample points of arable land, forest land and grassland in each region were listed in Table 1. The selected period of land use data was same with the soil data. The average annual temperature, annual average rainfall, soil texture, and SOC content were selected for use in the study.

## 2.3 Analytical method

The spatial pattern was quantified by the spatial variability of the SOC content using the semi-variant variance function. The semi-variant function is the key to the study of spatial variation, and the optimal model is used for

a kriging space interpolation. The method used to calculate the semi-variant function is as follows (Zhao et al., 2017):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2, \quad (1)$$

where  $\gamma(h)$  is a semi-variance function;  $[Z(x_i); Z(x_i + h)]$  is the measured value of two observation points with interval  $h$ ; and  $N(h)$  the number of pairs of all observation points in  $h$  as the step size. The semi-variance function diagram can be obtained by drawing  $h$ , and the most reasonable theoretical model can be obtained by fitting the semi-variance function according to the coefficient of determination  $R^2$  and the residual sum of squares (RSS).

The GS + software package (Gamma design software, Plainwell, MI, USA) was used to measure the geological statistical parameters that occur at a distance less than the sampling interval, including the block gold variance  $C_0$ , the structural variance  $C_1$ , and the spatial auto correlation length (range) from the fitted semi-variant function. The degree of spatial dependence (GD) is used to define different types of spatial dependency. If  $GD \leq 25\%$ , the variable is considered to have strong spatial dependence; if  $GD$  is between 25% and 75%, then the variable is considered to have moderate spatial dependence; and if  $GD \geq 75\%$ , the variable is considered to have weak spatial dependency. The spatial dependency is calculated as follows:

$$GD = \frac{C_0}{C_0 + C_1} \times 100\%. \quad (2)$$

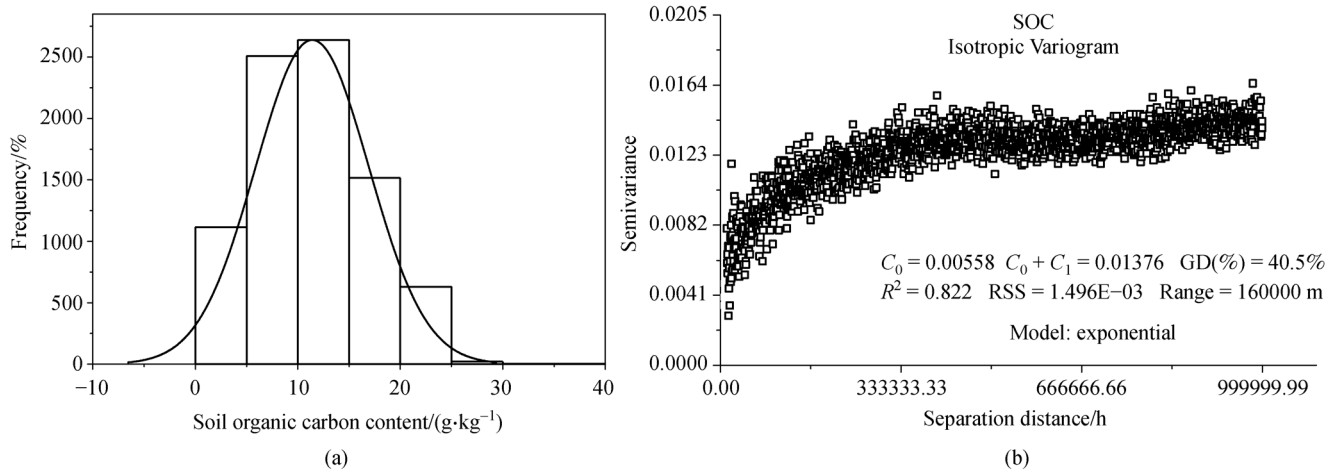
Table 2 compares theoretical semivariogram models and the determination coefficient  $R^2$  is the most important value to be considered, next at the residuals RSS values, and then the range and nugget (Liu et al., 2020). In this study, the optimal exponential model was selected as shown in Fig. 2.

## 2.4 Statistical analyses

The data was sorted using Excel (2010), and the semi-variance function was calculated using GS + (7.0). The spatial distribution map was constructed using ArcGIS (10.1), and the SOC content in the same land use mode of the same geographical area was analyzed by an analysis of variance (ANOVA) using the SPSS18.0 software. A partial correlation analysis was used to identify the effects of mean annual temperature (MAT) and mean annual precipitation (MAP) on SOC content, and a regression

**Table 1** The number of arable land, forest land and grassland sample points in each region

Type	Northwest	Northern	Southern	Qinghai-Tibet
Arable land	314	2210	2547	328
Grassland	248	333	118	175
Forest land	129	387	884	184



**Fig. 2** Semivariogram function theory model.  $C_0$ : nugget variance;  $C_1$ : structural variance; GD: degree of spatial dependence; RSS: residual sum of squares.

**Table 2** Semivariogram theoretical models of SOC content and the parameters

Theoretical Model	Nugget ( $C_0$ )	Sill Value ( $C_0 + C_1$ )	$C_0/(C_0 + C_1)$	RSS	Range	$R^2$
Spherical Model	0.150	0.031	0.476	$2.718 \times 10^{-3}$	269000	0.501
Gaussian Model	0.020	0.040	0.498	$9.076 \times 10^{-3}$	197000	0.654
Exponential Model	0.006	0.014	0.405	$1.496 \times 10^{-3}$	160000	0.822

Notes: RSS and  $R^2$  represent residual sum of squares and coefficient of determination.

analysis was used to determine the explanatory power of climate factors and soil texture on SOC content. Figures were drawn with Origin (8.0) software.

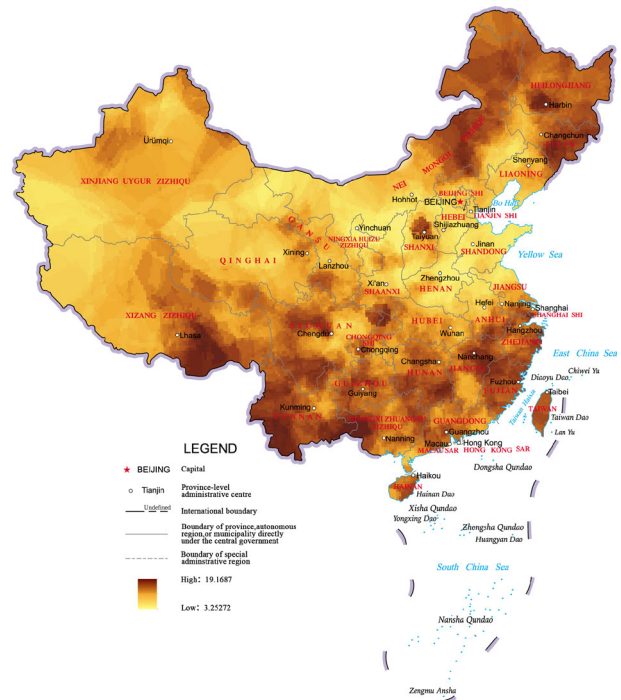
### 3 Results and analysis

#### 3.1 Distribution of SOC

The distribution of SOC in China is shown in Fig. 3, which shows that the SOC content was found to increase gradually from north to south, with a mean value of  $11.20 \text{ g} \cdot \text{kg}^{-1}$ . The regional SOC content in northern China was low, but the SOC content in northeast China was high. It has been reported that the minimum SOC content in northeast China is  $17.0 \text{ g} \cdot \text{kg}^{-1}$ , while the maximum value in the Loess Plateau is  $15.0 \text{ g} \cdot \text{kg}^{-1}$ . The regional SOC content in southern China was high. The Arable land in south China is mainly paddy fields. The SOC content in a paddy field layer is  $(18.26 \pm 7.06) \text{ g} \cdot \text{kg}^{-1}$  (Duan et al., 2012; Zeng et al., 2015), which is significantly higher than the content recorded in the northern dryland ( $11.63 \pm 5.65) \text{ g} \cdot \text{kg}^{-1}$  (Li et al., 2016). The different natural geographic regions were then studied in more detail.

#### 3.2 Geographical distribution of SOC

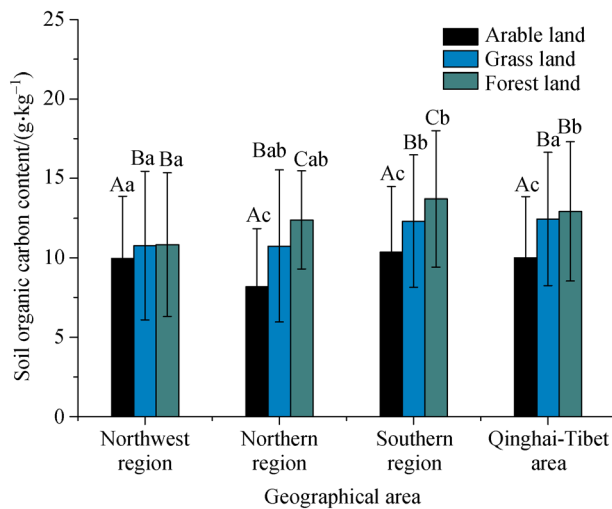
The SOC content in the different geographical zones of



**Fig. 3** Soil organic carbon (SOC) content and geographical divisions.

China is shown in Fig. 4. The SOC content of agricultural land in each geographical region was lower than that of

grassland and forest land ( $P < 0.05$ ). There was no significant difference in SOC content between grassland and forest land in northwest China and the Qinghai-Tibet region. The SOC content in northern and southern China was at its highest in forest land, and then followed by grassland. When the same land use was considered in each region, the SOC content of farmland was highest in the southern and Qinghai-Tibet areas ( $P < 0.05$ ), while the SOC content in the northern area was lower than that in other areas. The SOC content of forest land was highest in the southern China and Qinghai-Tibet regions, while it was lowest in northwest China ( $P < 0.05$ ). In summary, the return of cropland to forest or grassland can significantly



**Fig. 4** Soil organic carbon (SOC) content in each geographical zone. Note: uppercase letters represent the differences among the different land use types in the same area, and the lowercase letters indicate the differences in different areas of the same land use type.

increase the SOC content, improve the soil environment, and increase soil fertility.

### 3.3 Effect of climate on SOC content

Table 3 lists the correlation coefficients for the relationships between SOC and climate factors, and indicates the degree to which SOC content can be explained by climate factors. In northwest China, temperature and precipitation had significant effects on SOC. The degree to which temperature could explain the observed SOC was 99.9%, while precipitation could explain 88.5% of the SOC distribution. However, the impact of the interaction between the two climate factors was minimal, only explaining 8.8% of the SOC distribution. Temperature had a significant effect on SOC in northern China, while precipitation have no significant impact. The degree to which rainfall could explain the observed SOC was 89.7%, while the interaction of the two climate factors could explain 78.4% of the SOC distribution. In the southern region, the temperature only had a significant influence on the SOC content of grassland soil, while precipitation has a considerable impact on the SOC content of agricultural land. In the Qinghai-Tibet region, temperature and precipitation only had a significant effect on SOC in farmland, while rainfall could explain 87.9% of the SOC distribution.

Overall, temperature had a negative effect on SOC content, while precipitation had a positive effect. Under the different land use, the degree to which temperature, precipitation, and their interaction could explain the SOC distribution differed, but overall, although temperature played a specific role in the SOC content, precipitation was the most important climate factor influencing the SOC content.

**Table 3** Partial correlation and interpretation between soil organic carbon (SOC), mean annual temperature (MAT), and mean annual precipitation (MAP)

Area	Climate	Correlation coefficient			Efficacy analysis			
		Arable land	Grass land	Forest land	Arable land	Grass land	Forest land	Ensemble
Northwest	MAT	-0.295**	-0.471**	-0.694**	0.779	0.966	0.999	0.999
	MAP	0.197*	0.351**	0.469**	0.113	0.254	0.946	0.885
	MAT × MAP	-	-	-	0.059	0.131	0.954	0.088
Northern	MAT	-0.381**	-0.263*	-0.153*	0.999	0.846	0.727	0.104
	MAP	0.230	-0.030	0.220*	0.916	0.063	0.938	0.897
	MAT × MAP	-	-	-	0.823	0.050	0.076	0.784
Southern	MAT	-0.070	-0.363*	-0.058	0.539	0.881	0.420	0.05
	MAP	0.107**	0.142	0.088	0.995	0.467	0.590	0.997
	MAT × MAP	-	-	-	0.944	0.116	0.055	0.602
Qinghai-Tibet	MAT	-0.193*	-0.163	-0.093	0.934	0.385	0.058	0.545
	MAP	0.107**	0.200	0.154	0.923	0.490	0.177	0.879
	MAT × MAP	-	-	-	0.470	0.114	0.053	0.379

Notes: \*, \*\*, \*\*\*Significant at  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$ , respectively.

### 3.4 Effect of soil texture on SOC content

Table 4 lists the correlation coefficients for the relationships between soil SOC and soil texture factors under different land use patterns in different geographical areas. There was a significant positive correlation between SOC content and the silt and clay contents, and a significant negative correlation between SOC content and soil sand content ( $P < 0.001$ ).

The  $R^2$  value of the regression equation showed that there was no significant difference in the explanation of SOC content by soil texture (Table 5). There were various soil texture factors affecting SOC content in different land use patterns. For agricultural land, the soil texture factor that affected the SOC content in the northwest and Qinghai-Tibet regions was the clay content, while in the southern area it was the sand content, and in the northern zone the clay and sand content had a collective influence on the SOC content. The soil texture factors affecting the grassland SOC content in different geographical areas were also different. The northwest and southern regions were most affected by clay, while in the northern region it was sand, and in the Qinghai-Tibet region it was silt. The soil texture factors that most affected the SOC content of forest land in the northern, southern, and Qinghai-Tibet regions were sand particles, while in northwest China, it was silt particles.

### 3.5 Joint effect of climate and soil texture on SOC content

In a step-by-step regression analysis, the SOC content was used as the dependent variable, while MAP, MAT, sand, silt, and clay were independent variables. Table 6 lists the predictive factors that were entered into the model in a stepwise regression order. The  $\Delta R^2$  values changed with the entry of predictive variables into the model. The  $\Delta R^2$

value represents the contribution of a variable to the whole model. In the whole country, the highest explanatory power of SOC in agricultural land was found for the combination of climate and soil texture, which reached 88.6%, while the combination of atmosphere and soil composition was the lowest at only 17.1%. The highest explanatory power of SOC for grassland in the southern region was found for the combination of climate and soil texture, which reached 50.5%, while the same combination for forest land in the Qinghai-Tibet region could only explain 9.9%. The combination of climate and soil texture for forestland in northwest China had a joint explanatory power of 99.2%, while for forest land in southern China, it was only 7.7%. There was a regional difference in the importance of climate and soil texture for explaining the variability of the SOC content. The contribution of the climatic factors to  $R^2$  values in the different regions followed the order of Qinghai-Tibet (92.5%) > northwest (63.2%) > northern (52.1%) > south (34.9%). The contribution of soil texture to  $R^2$  values followed the order of south (65.1%) > north (47.9%) > northwest (36.8%) > Qinghai-Tibet (7.4%). Thus, it can be seen that the lower the temperature, the more significant the influence of environmental factors on SOC. In contrast, the higher the temperature, the greater the effect of soil texture on SOC.

## 4 Discussion

### 4.1 Spatial differences of SOC content

In this study, SOC in arable land in various geographical regions of China was found to be lower than that in grassland and forest land. SOC content depends on the balance between the input and decomposition of organic materials. In natural systems, the turnover of dead leaves

**Table 4** Correlation analysis between SOC content and soil texture factors in China

Area	Soil texture	Correlation coefficient		
		Arable land	Grass land	Forest land
Northwest	Sand	-0.248**	-0.184**	-0.510**
	Silt	0.140**	0.103**	0.613**
	Clay	0.317**	0.254**	0.089**
Northern	Sand	-0.273**	-0.500**	-0.344**
	Silt	0.186**	0.394**	0.309**
	Clay	0.266**	0.423**	0.304**
Southern	Sand	-0.271**	-0.103**	-0.190**
	Silt	0.243**	0.229**	0.152**
	Clay	0.184**	-0.209**	0.144**
Qinghai-Tibet	Sand	-0.148**	-0.325**	-0.371**
	Silt	-0.135**	0.331**	0.354**
	Clay	-0.109**	0.208**	0.306**

Notes: \*, \*\*, \*\*\*Significant at  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$ , respectively.

**Table 5** Stepwise regression analysis of SOC and soil texture factors in different land use patterns in different geographical areas

Area	Land use	Regression analysis <sup>a)</sup>	
		$R_{adj}^2$ <sup>b)</sup>	Equation
Northwest	Arable land	0.317**	SOC = 6.567 + 0.201 × Clay
	Grass land	0.254**	SOC = 6.113 + 0.176 × Clay
	Forest land	0.614**	SOC = 3.927 + 0.266 × Silt
Northern	Arable land	0.289**	SOC = 9.006 + 0.750 × Clay - 0.470 × Sand <sup>c)</sup>
	Grass land	0.500**	SOC = 19.854 - 0.171 × Sand
	Forest land	0.344**	SOC = 19.609 - 0.137 × Sand
Southern	Arable land	0.271**	SOC = 16.335 - 0.075 × Sand
	Grass land	0.120**	SOC = 3.719 - 0.910 × Clay
	Forest land	0.190**	SOC = 16.367 - 0.057 × Sand
Qinghai-Tibet	Arable land	0.313**	SOC = 6.567 + 0.810 × Clay
	Grass land	0.331**	SOC = 5.886 + 0.131 × Silt
	Forest land	0.371**	SOC = 3.307 + 0.108 × Sand

Notes: \*, \*\*, \*\*\*Significant at  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$ , respectively. <sup>a)</sup> The dependent variable was SOC, and the independent variables were centered log-ratio transformation values of the sand, silt, and clay contents. <sup>b)</sup> Adjusted coefficient of determination. <sup>c)</sup> When just sand entered the model, the equation was in the form of SOC = 11.944 - 0.07 × sand with  $R_{adj}^2 = 0.273$ .

**Table 6** Results of a stepwise regression analysis of SOC and climatic texture in different geographical regions of China

Area	Land use	Stepwise regression model <sup>a)</sup>	$R_{adj}^2$ <sup>c)</sup>	$\Delta R_1^2$ <sup>d)</sup>	$\Delta R_2^2$ <sup>e)</sup>	$\Delta R_3^2$ <sup>f)</sup>	$\Delta R_4^2$ <sup>g)</sup>
Northwest	Arable land	Constant, Clay, MAT, Silt	0.491	0.094	0.187	0.21	
	Grass land	Constant, MAT, Clay	0.486	0.215	0.271		
	Forest land	Constant, MAT, Silt	0.992	0.471	0.521		
Ensemble		Constant, MAT, Sand, MAP	0.719	0.171	0.264	0.284	
Northern	Arable land	Constant, MAT, Sand, Clay, MAP	0.886	0.145	0.242	0.248	0.251
	Grass land	Constant, Sand, MAT	0.519	0.244	0.275		
	Forest land	Constant, Sand, MAP	0.266	0.118	0.148		
Ensemble		Constant, Sand, MAT	0.497	0.238	0.259		
Southern	Arable land	Constant, Sand, MAP	0.171	0.073	0.098		
	Grass land	Constant, MAT, Silt, MAP	0.505	0.117	0.164	0.224	
	Forest land	Constant, Sand, MAP	0.077	0.034	0.043		
Ensemble		Constant, Sand, MAP, Silt	0.798	0.235	0.279	0.284	
Qinghai-Tibet	Arable land	Constant, MAP, MAT, Clay	0.419	0.076	0.156	0.187	
	Grass land	Constant, Silt	0.099	0.099			
	Forest land	Constant, Sand	0.126	0.126			
Ensemble		Constant, MAP, Sand, MAT	0.494	0.195	0.232	0.262	

Notes: <sup>a)</sup> The dependent variable was SOC, and the independent variables were mean annual temperature (MAT), mean annual precipitation (MAP), and the centered log-ratio transformation values of the sand, silt and clay content. <sup>b)</sup> Adjusted coefficient of determination ( $R_{adj}^2$ ). <sup>c)</sup> Variables finally entering the model in the correct order. <sup>d)</sup> Change in  $R^2$  caused by the first variable entering the model. <sup>e)</sup> Change in  $R^2$  caused by the second variable entering the model. <sup>f)</sup> Change in  $R^2$  caused by the third variable entering the model. <sup>g)</sup> Change in  $R^2$  caused by the fourth variable entering the model.

and the micro-root system is the main pathway for soil organic matter inputs (Chen et al., 2013). SOC is also lost as a result of tillage, soft soil textures, strong water erosion, and serious soil erosion. Artificial tillage increases soil permeability, and mature crop harvesting prevents the C in

crops from being returned to the soil. These factors contribute to the adverse effects of agricultural land on SOC accumulation and conservation (Zhang et al., 2019). Compared with arable land, in forest and grassland litter, exogenous C inputs accumulate on the soil surface and

provide sufficient energy and material sources for microbial activities, which will promote biological activity in the soil surface layer (Xu et al., 2018). Because the degree of human disturbance in forest and grassland is lower than that of farmland, there will be an effect on the mineralization, transportation, absorption, and utilization of soil C, which will eventually lead to differences in the SOC content (Miegroet and Olsson, 2011).

The forest and grassland in the northwest China and Qinghai-Tibet regions were largely created by the conversion of cropland but the recovery time has been relatively short. In terms of vegetation succession, the forest land has not reached the highest stage of succession, and therefore there was no significant difference in the SOC content between grassland and forest land. However, there are abundant forest and grassland resources in the north and south of China, and most of them are natural. They are older than the grassland and forest areas in the northwest and Qinghai-Tibet regions. Therefore, the SOC content was at its highest in forest land, and then followed by grassland (Wang et al., 2017).

From a national overview, the farmland SOC content was lowest in the northern region. This may be related to the farming methods adopted. The north is mainly a dry land-based agricultural region, the south is mainly a paddy field-based agricultural region, the northwest is mainly livestock and irrigated agricultural region, and the Qinghai-Tibet region is mainly a high-cold farming and pastoral area. Dry land agriculture mainly depends on natural precipitation to sustain crops. Compared with other farming methods, the SOC has a lower cycling capacity, and dry land farming is therefore not conducive to the accumulation of SOC. Therefore, the SOC content of farmland soil was lowest in the northern region. The SOC content of forest land and grassland was highest in southern China. Vegetation is one of the primary means to control soil erosion, and can effectively slow down the development of eroded soil (Zhou et al., 2016), improve soil fertility (Zhang et al., 2018), enhance soil microbial activity (Zhao and Li, 2017), and affect the soil C cycle. Therefore, vegetation has a specific effect on the SOC pool, nitrogen accumulation, and greenhouse gas emissions.

#### 4.2 Factors influencing SOC Content

The relationship between climate and SOC is very complicated, and therefore the influence of climate change on SOC and its feedback effect on climate change is also very complex (Follett et al., 2015). The increase in temperature and precipitation can increase the photosynthesis and water use efficiency of plants and increase the net primary productivity and C fixation of plants; thus, increasing the number of plant residues in the input soil and increasing the SOC content in the input soil. An increase in temperature and rainfall can also enhance soil

microbial and animal activities, increase the soil respiration rate, and accelerate the decomposition of SOC (Zhang et al., 2019). Therefore, an increase in temperature and rainfall does not necessarily mean an addition of SOC. It was found that precipitation spatial variability strongly dominates modes of C variability across space (Mehta et al., 2014). Significant sustained changes in precipitation are likely to lead to shifts in system structure and function. Taking forestland as an example, reduction of precipitation could lead to lower species diversity, biomass and height, leading to decline in litter input, and eventually decreased in SOC. And water addition accelerated plant residue incorporation into soil organic matter (Wang et al., 2015). The same is true of grassland and farmland, it shown as positive relationship between SOC and land use types. But microbial activity is also significantly stimulated by water addition and decomposes SOC into CO<sub>2</sub>, CH<sub>4</sub>, etc. This indicate that higher precipitation may result in enhanced soil C inputs but not necessarily increase soil C storage, as previously observed by, for example, Casals et al. (2011). We found that precipitation was the most critical climate factor determining the level of SOC, while temperature plays a crucial role in certain regions (Table 2). Moreover, there are studies suggested that temperature have larger correlation with SOC (Nie et al., 2021). Temperature can affect SOC in two ways: 1) warming reduces SOC accumulation by accelerating the microbial decomposition of SOC; 2) It also contributes to SOC accumulation by stimulating aboveground biomass production, resulting in a greater C input into soil. The two opposite ways may define the negative or positive effects of temperature on SOC. Researchers have studied the temperature sensitivity of SOC decomposition based on Q10 values, i.e., the rate of change of soil respiration per 10°C of temperature increase (Jia et al., 2020). The results indicated that chemical protection (mineral protection) of SOC may be weaken with increasing temperature because it may enhance the activity of specific microbial groups and enzymes (Razavi et al., 2017), leaving protected C available for microorganisms. Physical protection (aggregated protection) of SOC, on the contrary, is independent of temperature. Chen et al. (2005) indicated that the temperature sensitivity index of SOC decomposition is lower in low latitudes, but higher in cold high locations with the Q10 value gradually increasing in larger areas. The Qinghai-Tibet region is a high latitude region. When the temperature decreases, photosynthesis is weakened, the amount of litter input to the soil is reduced, and the SOC is reduced (Table 3). The southern region of China is in the lower latitudes, where the opposite pattern applies. With an increase in altitude, the effect of temperature on SOC gradually changes. The SOC content is affected by the combination of temperature and precipitation. The effects of temperature and precipitation on soil include changes in the input and decomposition of SOC. Their effects on soil are also closely related to the geographical location,

topography, parent rock, vegetation type, and other factors (Chen et al., 2013). The impact of different temperatures and rainfall combinations on SOC in different regions is not consistent.

In this study, it was found that the SOC were all negatively correlated with the sand content (Table 4). This indicates that the higher the clay and powder content, the higher the SOC content, and the higher the sand content, the lower the SOC content. This was consistent with previous studies (Schimel et al., 1994; Chang et al., 2019; Zhang et al., 2019). This is mainly because clay and silt can promote the deposition of SOC, and the ability of sand to bind to SOC is weakened due to its large specific surface area, which leads to the decrease of SOC content (Balesdent et al., 1998). Although there was no significant difference in the SOC interpretation, the soil texture factors affecting SOC content in different land use patterns in other geographical areas were various. For example, the soil texture factors affecting the SOC content of forest land in the northern region, the southern region, and the Qinghai-Tibet region are sand grains. In contrast, the northwest region is silt grains. Compared with agricultural land, it can be found that the soil texture factors affecting the SOC content in northwest China and Qinghai-Tibet region are the clay, and the southern region is sand, while the northern region clay and sand jointly affect the SOC content in this area. It can be seen that the effects of soil texture on SOC are different under different land use methods in other regions. In our opinion, this phenomenon is that the soil in different regions is mainly inherited from the types and characteristics of the parent material and is also affected by human factors such as tillage, fertilization, drainage and irrigation, land leveling, and so on (Shah et al., 2014). Therefore, according to our research results, we can put forward corresponding measures to increase fertility. Taking arable land as an example (Table 5), the soil texture factor of SOC content in northwest China and the Qinghai-Tibet region is clay, which is rich in soil nutrients and has high organic matter content (Zhang et al., 2019). Therefore, most soil nutrients are not easily lost by rain water and irrigation water, so the fertilizer retention performance is good, but when rain or irrigation, water is often challenging to infiltrate in soil, which leads to drainage difficulties, and additionally affects the growth of crop roots and hinders the absorption of soil nutrients by roots (Chang et al., 2019). For this kind of soil, we should pay attention to drainage in production, reduce groundwater level to avoid or reduce waterlogging, and select intensive tillage under suitable soil water-bearing conditions to improve soil structure and tillage property to promote the release of soil nutrients. In the southern region, sand grains have weak drought resistance, easy leakage, and leakage of fertilizer. So, the soil nutrients are less, coupled with the lack of clay and organic matter. The fertilizer retention performance is weak, and the available fertilizer is easily lost with Rain Water and irrigation water.

Therefore, the sand should emphasize increasing the application of organic fertilizer. It also needs timely topdressing, and mastering the principle of diligent watering and thin application. The clay and sand in the northern area affect the SOC content in the area. This area has the advantages of sand and clay, which is more ideal soil has excellent cultivability and a wide variety of crops suitable for planting.

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## 5 Conclusions

SOC content in China, with a mean value of  $11.20 \text{ g} \cdot \text{kg}^{-1}$ , increased gradually from north to south. The SOC differences with different land use and regions are significant ( $P < 0.05$ ). The SOC content of arable land in each geographical region was lower than that of grassland and forest land ( $P < 0.05$ ), while the SOC in northeast region was highest. The implementation of returning farmland to the forest (grass) can significantly increase SOC content, improve the soil environment, and increase soil fertility. The SOC content was positively correlated with silt and clay content and negatively correlated with soil sand. But for three land use types in each region, the soil texture factors affecting SOC was different. Although temperature also plays a specific role in the range of SOC, precipitation is the most critical climate factor determining the content of SOC, which could explain more than 87% of the SOC distribution in China. There was a regional difference in the importance of climate and soil texture for explaining the variability of the SOC content. The contribution of the climatic factors to  $R^2$  values in the different regions followed the order of Qinghai-Tibet (92.5%) > northwest (63.2%) > northern (52.1%) > south (34.9%), and that for soil texture was south (65.1%) > north (47.9%) > northwest (36.8%) > Qinghai-Tibet (7.4%). The lower the temperature, the greater the effect of environmental factors on SOC. On the contrary, the higher the temperature, the more significant the impact of soil texture on SOC.

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