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The distribution variation and key influencing factors of soil organic carbon of natural deciduous broadleaf forests along the latitudinal gradient

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ABSTRACT

Soil organic carbon plays a key role in soil carbon stock in response to global climate changes. Forests are considered to be an important resource in contributing to mitigating the carbon cycling. Therefore, forest soils should be paid more attention in exploring soil organic carbon on a regional scale. The aim of this study is to explore the variation trend of soil organic carbon content and environmental impact in natural deciduous broadleaf forests along a north-south latitudinal gradient in China. Soil organic carbon showed a significantly ($P < 0.05$) decreasing trend with the latitude increasing, similar observation to total nitrogen. Partial Pearson correlation analysis indicated that total nitrogen was the most positively ($R = 0.91$) and significantly ($P < 0.05$) correlated with soil organic carbon, which indicated close coupling between carbon and nitrogen in soil. The climate, soil pH and plants were also the key factors in influencing the distribution of soil organic carbon.

1. Introduction

Soil is the largest terrestrial carbon pools in the biosphere [1]. The abundance of soil carbon influences plant production, also influenced by plant communities as an important control of soil fertility [2]. Soil organic carbon plays key roles in the functions of forest ecosystem, global carbon cycle, and its potential for influencing atmospheric levels of greenhouse gases, especially in global climate warming. Generally, soil organic carbon was found to about three times the amount of organic carbon in vegetation globally [3], which played a vital role in carbon exchange with the air through photosynthesis and respiration [4]. Soil organic carbon changes from place to place, and its spatial variation is the basic pertinent information for forest management and modeling soil carbon storage changes [5]. Small changes in carbon input and decomposition could lead to great changes of carbon dioxide (CO_2) globally [6]. Therefore, it is important to understand the distribution and regulation of soil organic carbon in forest ecosystems [7], contributing to establish a series of relevant dataset based on reliable estimates of the current carbon content.

Studying the distribution and environmental impact of soil organic carbon along the large geographic variation contributes to make certain measures for raising soil-stored carbon and reducing atmospheric carbon release. Global climate changes, as the variations in temperature, precipitation and atmospheric CO_2 concentration, could significantly change terrestrial carbon storage [8]. To this regard, soil organic carbon should be paid more attention. Many studies found that organic carbon could be influenced by many environmental variables, such as forest types [9], total nitrogen [10], moisture [11], temperature [12], altitude [13]. Hobbie S.E. et al. reported that controls of carbon storage and turnover in high-latitude soils were closely linked with plant litter decomposition, cold temperature, and biological activities [14]. Jobbágy E.G. et al. explored the vertical distribution of soil organic carbon using >2700 soil profiles, indicated that plant functional types and climate significantly influenced soil organic carbon distribution [8]. Jackson R.B. et al. examined above- and belowground allocation patterns of soil organic carbon, showing differences among distinct vegetation types [15]. Dianwei Liu et al. found that the spatial variability of soil organic carbon was consistent with the spatial structure of topography and land use type at 354 locations in croplands of the black soil region in China [16]. Xuan Fang et al. investigated that soil organic carbon distribution was influenced by land use in a small watershed of the Loess Plateau of China [17]. Despite a great deal of research done, however, no clear research regarded the distribution pattern and environmental impact of soil organic carbon in natural deciduous broadleaf forests along the latitudinal gradient from the north to the south in China.

Broadleaved forest is the primary vegetation type of terrestrial environments with the highest detectable vegetation density [18], which has been extensively investigated in regard to plant distribution patterns, physiological characteristics, and the nutrient dynamics [19]. In

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the present study, soil samples were taken from the representative natural broadleaf forests for soil organic carbon analysis in China. We mainly focus on the distribution pattern and environmental impact of soil organic carbon on a large scale along the latitudinal gradient.

2. Materials and methods

2.1. Site description

The study areas were located in mainland China, ranging from 40° N to 24° N. Total of 22 study sites were selected along the latitudinal gradient from the north to the south in China (Table 1, Fig. 1), with few changes in soil texture, slope, and aspect. These sites were Daqiangshan (DQS), Luyashan (LYS), Pangquangou (PQG), Huanglongshan (HLS), Lishan (LS), Manghe (MH), Xiaoqinling (XQL), Longyuwan (LYW), Nanzhao (NZ), Baotianman (BTM), Duheyuan (DHY), Houhe (HH), Mulinzi (MLZ), Hupingshan (HPS), Badagongshan (BDGS), Mayanghe (MYH), Baiyunshan (BYS), Fanjingshan (FJS), Huangsang (HS), Maoershan (MES), Huaping (HP) and Dayaoshan (DYS) in China. Study sites were randomly chosen to present the major landform and vegetation types of deciduous broadleaf forests within the designed grids, taking into account the logistical problem of accessing these sites. Both annual mean temperature (AMT) and annual mean precipitation (AMP) were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid [20]. The AMT and AMP of study sites ranges from 1.50 °C to 14.50 °C and from 381 mm to 1648 mm, respectively.

2.2. Soil sampling and experimental analysis

Soil samples were investigated in mainland China dating from August to October in 2012. At each site, with more complex topography, 10 plots (20 m × 20 m) were established in an approximate area covering 2.5 ha^2, with a distance of about 20 m between adjacent plots. Total of 220 soil samples in 22 forest sites were investigated at 0–10-cm depth of the surface soils, which is sensitive to external interferences. Soil samples were sieved using a 2-mm mesh in order to remove roots and stones, homogenized and archived at 4 °C for physicochemical analysis. The latitude, longitude, and altitude (ALT) were determined by a global positioning satellite (GPS) receiver (5-m precision) at each sampling site. The properties of plant communities were also recorded in the sampling process, including plant (arbor, shrub and herbage) species, diameter at breast height (DBH) or ground diameter, plant height and number.

Soil samples were air-dried and crushed to either 2 mm or 0.15 mm mesh for experimental analysis. Soil properties were measured as previously described methods [21], including of soil organic carbon (SOC) and total nitrogen (TN). SOC was measured by dichromate oxidation [22]. Specific steps as followed: firstly, acidification soil samples was put into 150 ml triangle flask, added 5 ml concentrated sulfuric acid, left for 1 h, and added 5 ml of 0.8 M potassium dichromate; Then we put them into the phosphoric acid to digestion in the condition of 180 °C, till the boiling for 5 min, took out of them and till cooling; Finally, using the titration method to measure SOC. TN was determined by Kjeldahl digestion procedure [23]. Soil pH was measured at a water-to-soil mass ratio of 2.5:1 by a pH meter with a calibrated combined glass electrode [24]. Soil temperature (TE) was measured using a Hobo Temperature instrument at the depth of 10 cm. Soil moisture (MO) was determined gravimetrically by weighing, after drying in an oven at 105 °C for 8 h.

2.3. Statistical analyses

Plant species diversity was characterized by Shannon's index based on the important value matrix of plant species. Partial Pearson correlation analysis was used to conduct the relationships between soil organic carbon and environmental variables. The linear regression analysis and regression model were determined to quantify the relationships between soil organic carbon and environmental variables. All these statistical and graphic analyses were performed by SPSS (v.19.0, IBM) and Sigmaplot (v.12.5) software, respectively.

3. Results and discussions

3.1. Basic environmental characteristics

Table 1 and Table 2 showed the basic environmental characteristics of 22 forest sites along the latitudinal gradient from the north to the south in China. Both annual mean temperature and annual mean precipitation had an increasing trend from the north to the south along

Table 1
Basic characteristic of 22 forest sites along the latitudinal gradient.

Sampling sites	Dominant plants	GPS	AMT (°C)	AMP (mm)	ALT (m)
DQS	*Quercus liaotungensis-Artemisia vestita-Cleistogenes squarrosa*	N40°50′/E110°15′	1.50	381	1677
LYS	*Quercus liaotungensis-Artemisia vestita-Carex tristachya*	N38°43′/E110°58′	3.70	493	1780
PQG	*Quercus liaotungensis-Rosa davurica-Carex tristachya*	N37°53′/E110°28′	3.10	537	1888
HLS	*Quercus liaotungensis Koidz-Spiraea pubescens-Elymus dahuricus*	N35°42′/E110°02′	7.85	574	1544
LS	*Quercus liaotungensis-Forsythia suspense-Carex rigescens*	N35°25′/E112°01′	6.66	705	1605
MH	*Carya cathayensis-Acer davidii-Carex rigescens*	N35°15′/E112°23′	9.11	685	1403
XQL	*Quercus liaotungensis-Forsythia suspense-Carex rigescens*	N34°26′/E110°30′	7.60	799	1771
LYW	*Quercus aliena-Rhododendron Simsii Planch-Armgrass*	N33°40′/E110°48′	6.40	976	1756
NZ	*Quercus chenii-Rhododendron Simsii-Carex rigescens*	N33°30′/E111°56′	9.20	905	1245
BTM	*Quercus aliena-Forsythia suspense-Carex rigescens*	N33°30′/E111°56′	8.10	948	1402
DHY	*Bothrocaryum controversum-Celastrus orbiculatus-Aster ageratoides*	N31°32′/E110°01′	9.00	1268	1798
HH	*Sycopsis sinensis-Yushania canoviridis-Ophiorrhiza cantoniensis*	N30°05′/E110°33′	11.18	1466	1568
MLZ	*Cyclobalanopsis glauca-Schima parviflora-Ainsliaea latifolia*	N30°04′/E110°13′	10.20	1515	1466
HPS	*Salix phaidima-Weigela japonica-Fargesia spathacea*	N30°03′/E110°32′	9.10	1542	1823
BDGS	*Cyclobalanopsis multinervis-Yushania canoviridis-Ophiopogonjaponicus*	N29°46′/E110°04′	11.56	1527	1453
MYH	*Quercus acutissima-Lindera glauca-Parathelypteris nipponica*	N28°42′/E108°12′	12.88	1337	1133
BYS	*Schima argentea-Rhododendron stamineum-Rhizoma Cibotii*	N28°41′/E109°19′	14.28	1415	1068
FJS	*Phoebe zhennan-Quercus phillyraeoides-Woodwardia japonica*	N27°53′/E110°44′	14.24	1261	1046
HS	*Schima argentea-Indosasa shibataeoides-Woodwardia japonica*	N26°24′/E110°05′	14.50	1485	1055
MES	*Daphniphyllum macropodum-Indosasa shibataeoides-Carex cruciata*	N25°54′/E110°28′	12.56	1637	1248
HP	*Schima argentea-Indosasa shibataeoides-Woodwardia japonica*	N25°34′/E109°56′	13.00	1646	1211
DYS	*Meliosma squimulata-Frgesia spathacea-Plagiogyria japonica*	N24°10′/E110°14′	14.20	1648	1514

22 forest sampling sites: Daqiangshan (DQS), Luyashan (LYS), Pangquangou (PQG), Huanglongshan (HLS), Lishan (LS), Manghe (MH), Xiaoqinling (XQL), Longyuwan (LYW), Nanzhao (NZ), Baotianman (BTM), Duheyuan (DHY), Houhe (HH), Mulinzi (MLZ), Hupingshan (HPS), Badagongshan (BDGS), Mayanghe (MYH), Baiyunshan (BYS), Fanjingshan (FJS), Huangsang (HS), Maoershan (MES), Huaping (HP), and Dayaoshan (DYS). AMT means mean annual temperature, AMP means annual mean precipitation, and ALT means altitude.