Distribution characteristics and influencing factors of soil organic carbon in alpine desert ecosystem of Qinghai Province

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Abstract

Alkaline deserts soils acted as important soil pools in arid and semiarid regions. Contents of soil organic carbon (SOC) and its driven factors remained still not clear in alpine deserts on the Tibetan Plateau. In this study, we analyzed 223 soil organic carbon contents and total nitrogen and pH values, and its space distribution pattern under 0-30 cm. It was indicated that average and median SOC were approximate 4.86 and 3.80 g/kg with variation coefficient of 81.14%. SOC contents ranged from 0.54 to 24.34 g/kg. Soils organic carbon contents were divided into four groups. The largest group was around 3.32 g/kg (145 sites) when air temperature and altitude were higher than 1.49 oC and 2793 m. Alpine desert SOC were mainly controlled by total nitrogen (TN) and pH and precipitation with R2 of 0.87 (P<0.001). Furthermore, soil pH was positively affected by air temperature not precipitation (P<0.05). Models may predict SOC through precipitation, air temperature and altitude (R2= 0.40, P<0.001). In addition, increasing regional precipitation perhaps decreased desert soils organic carbon storage in future climate scenarios.

Distribution characteristics and influencing factors of soil organic carbon in alpine desert ecosystem of Qinghai Province

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Abstract: Alkaline deserts soils acted as important soil pools in arid and semiarid regions. Contents of soil organic carbon (SOC) and its driven factors remained still not clear in alpine deserts on the Tibetan Plateau. In this study, we analyzed 223 soil organic carbon contents and total nitrogen and pH values, and its space distribution pattern under 0-30 cm. It was indicated that average and median SOC were approximate 4.86 and 3.80 g/kg with variation coefficient of 81.14%. SOC contents ranged from 0.54 to 24.34 g/kg. Soils organic carbon contents were divided into four groups. The largest group was around 3.32 g/kg (145 sites) when air temperature and altitude were higher than 1.49 °C and 2793 m. Alpine desert SOC were mainly controlled by total nitrogen (TN) and pH and precipitation with R^2 of 0.87 ($P<0.001$). Furthermore, soil pH was positively affected by air temperature not precipitation ($P<0.05$). Models may predict SOC

through precipitation, air temperature and altitude (R^2= 0.40, P<0.001). In addition, increasing regional precipitation perhaps decreased desert soils organic carbon storage in future climate scenarios.

Key words: SOC, alpine deserts, precipitation, generalized additive models

Introduction

Global mean temperature was 1.2 ± 0.1 °C above the 1850–1900 baseline in 2020, the past six years have been the six warmest years on record (WMO 2020). Increasing atmosphere greenhouse gases have been the major driver of global warming due to anthropogenic activities (Bossio et al., 2020, Topa et al., 2021).

Increasing soil carbon is an appealing way to prevent carbon emissions (Bossio et al., 2020, Feyissa et al., 2021). Soil organic carbon (SOC) may represent 25% of the potential of natural climate solutions (Bossio et al., 2020). Chinese land biosphere was a robust sink of 1.11 ± 0.38 petagrams of carbon, and Tibetan Plateau ecosystems covered about 10% (Wang et al., 2020). Alpine soils are increasingly recognized for carbon sequestration in high-altitude ecosystems (Liu et al., 2016, Du et al., 2019, Zhou et al., 2021). Natural desert lands contain some 7.84 petagrams of organic carbon in China (Feng et al., 2002). Deserts soil organic carbon contents were 4.37, 2.12 and 1.50 g/kg in the northwestern China, Norwest Mexico and Israel Negev desert (Mamat et al., 2011, Drahorad et al., 2013, Ayala-Nino et al., 2020).

Soil family types and land use were main driver factors on SOC contents and storage (Bai and Zhou 2020, Vries et al., 2020). Grassland types affected ecosystem carbon densities and contents (Liu et al., 2016, Du et al., 2019). Root-derived inputs are major contributors to soil carbon in temperate land ecosystems (Keller et al., 2021). Increased soil available nutrients had higher positive effects on carbon contents (Topa et al., 2021). Improving N-use efficiency are important for decreasing soil carbon losses from acidification (Frac et al., 2020, Raza et al., 2020). Soil nitrogen nitrification and denitrification rates increased significantly with pH (Drahorad et al., 2013, Feyissa et al., 2021). Addition of minimum temperature led to a significant increase in soil carbon sequestration capacity (Zhou et al., 2021). Desert grasslands SOC decreased with mean annual temperature, but increased significantly with annual precipitation (Feng et al., 2002, Drahorad et al., 2013, Wang et al., 2014). Greenhouse gas emissions from peatlands drained for agriculture could be greatly reduced (Cooper et al., 2020, Evans et al., 2021). Temperature and precipitation interaction significantly affected SOC density in alpine steppe (Liu et al., 2016).

Qaidam Basin covered an area over 250,000 km^2 (Tan et al., 2009). However, SOC contents distribution characteristic and its driven factors were underlying indistinct on the Tibetan Plateau. In this study, we hypothesized that significant regional variability changes in SOC contents in Qinghai. Moreover, soil pH and precipitation and air temperature significant affected SOC contents in alpine deserts.

2. Material and methods

2.1 Study area and sites

Location of 223 sample sites and main vegetation types were described in Qinghai Plateau including alpine desert, alpine steppe, alpine meadow and without vegetation (Fig. 1). This study was conducted in alpine desert ecosystem with a plateau continental climate. Average air temperature and precipitation were -3.68 °C and 92.94 mm. Altitude ranged from 2600 to 3200 m. Soil types mainly included grey-brown desert soil, aeolian sandy soil, and saline alkali soil.

Alpine deserts were dominated by *Kalidium foliatum (Pall.) Moq., Sympegma regelii Bunge, Nitraria tangutorum Bobr., Salsolacollina Pall., Artemisia sphaerocephala Krasch., Tamarix chinensis Lour., Ceratoides latens, Ephedra przewalskii Stapf, Haloxylon ammodendron Bunge, Reaumuria kaschgarica Rupr., Reaumuria songarica, Peganum harmala, Lyciumchinense Miller.*

2.2 Experimental design and analysis method

Qaidam Basin was dominated by alpine deserts, we selected typical deserts soil samples soil nearly 10 km upper 30 cm mixture. Thus, all 223 observations were collected in this study (Fig. 1). Samples were deposited for air drying, and then passed through a 0.25 mm soil mesh sieve.

Soil organic carbon contents were analyzed by TOC-5000A analyzer (Shimadzu corporation, Japan) using dry oxidation method. TN and TP were analyzed by Elemental Analyzer (PE2400IICHN, German) and perchloric acid sulfuric acid dissolution molybdenum antimony anti colorimetry. Furthermore, pH was measured by automatic titrator with a pH (H_2O) probe (PHS-3C, China). Altitudes were tested by global positioning system (GPSMAP 66s, China). Average monthly climate data (January 2020) is downloaded from http://worldclim.org for 1970-2000 with 1 km^2 spatial resolutions (Fick and Hijmans 2017).

Statistics

Cluster analysis of SOC and TN were conducted by multivariate regression trees through "mvpart" package in R-3.3.4 version. Drive factors of climate factors and soil characteristics on SOC and TN were analyzed by structural equation model using "piecewiseSEM" package. SOC contents were predicted based on climate factors by generalized additive models (mgcv).

3. Results

3.1 Variation in alpine desert SOC and TN and TP in Qinghai Plateau.

Averaged SOC was approximate 4.86 +- 0.26 g/kg with high variation coefficient around 81.14% in Qaidam Basin (Table 1). Median value of SOC was 3.80 g/kg and ranged from 0.54 to 24.34 g/kg with 15 outlier values over 11.2 g/kg (Figure 2).

Mean total nitrogen was around 4.62 +- 0.25 g/kg with much high variation coefficient around 82.95% (Table 1). Median value of total nitrogen was 3.64 g/kg ranging from 0.67 to 27.69 g/kg with 17 extreme outlier values over 10.0 g/kg. Mean and median value of total phosphorus were 5.20 +- 0.09 and 5.45 g/kg with low variation coefficient ranging from1.81 to 10.67 (Figure 2).

3.2 Cluster analysis of SOC and TN by multivariate regression trees

Both soils organic carbon contents and total nitrogen were divided into four groups. The largest group was around 3.32 g/kg (145 sites), when precipitation was lower than 371.5 mm. Meanwhile, air temperature and altitude were higher than 1.49 °C and 2793 m (Figure 3). The second group was approximate 6.48 g/kg including 52 sample sites when air temperature was lower than 1.49 °C. SOC contents were relative higher about 13.7 g/kg when precipitation was 371.5 mm.

The largest group included 161 sample sites approximate 3.48 g/kg of total nitrogen when precipitation was under 371.5 mm, and temperature was higher than 1.49 °C. Meanwhile, altitude threshold was 3655 m. Total nitrogen was nearly 12.8 g/kg at higher altitude. Furthermore, soil total nitrogen seemed higher under higher altitude and lower temperature conditions.

3.3 Structural equation model revealed main affected factors on desert SOC and TN and pH

Desert SOC were mainly affected by TN, pH and precipitation using structural equation model with R^2 of 0.87 among six factors (Figure 4). Affected coefficients of TN and pH and precipitation were 0.99 and -0.21 and -0.16, separately ($P<0.001$). However, total phosphorus and altitude and air temperature took weak roles in affecting SOC contents. Soil total nitrogen contents were positively driven by precipitation with effect coefficient of 0.37 ($P<0.001$). Both temperature and altitude took weakly negative role in soil nitrogen. Furthermore, air temperature affected positively soil pH ($P<0.05$).

3.4 Predictions of SOC based on climate factors by generalized additive models in Qaidam basin

This generalized additive model could accurately predict soil organic carbon contents using air temperature and precipitation and altitude data with R^2 of 0.40 ($P<0.001$). All three factors took significant effect on soc contents (Figure 5). In addition, contribution were precipitation, temperature and altitude by turn.

4. Discussion

4.1 Soil organic carbon contents and its space patters in desert ecosystems

Paris Agreement aimed to hold air temperature below 2 degC above pre-industrial levels (WMO 2020). Protecting SOC pools could deliver many benefits to nature ecosystems and people (Bossio et al., 2020, Vries et al., 2020). Land biosphere absorbed approximately 45% of annual anthropogenic carbon emissions in China (Wang et al., 2020). Potential SOC stock would increase by 0.83 petagrams due to grassland restoration on Tibetan Plateau (Du et al., 2019).

Soil organic carbon and microbial biomass carbon contents varied remarkably among the different species communities in desert grasslands and shrubs (Mamat et al., 2011, Zhang et al., 2019). Average SOC contents of nondegraded and degraded grasslands were 34 and 24 g/kg on Tibetan Plateau (Du et al., 2019). SOC was 25.01 g/kg with 55.26% variation coefficient in karst mountainous area indicating moderate variation (Bai and Zhou 2020). Deserts soil organic carbon contents were 7.05, 3.94 and 1.56 g/kg in West Jilin Province and Inner Mongolia and Tarim Basin in China (Feng et al., 2002). Furthermore, desert soil organic carbon was 5.47 and 5.30 g/kg across Central Iran and India salt deserts, separately (Motaghian and Mohammadi 2012, Datta et al., 2020). It was indicated that deserts soc presented spatial heterogeneity.

In this study, desert soil organic carbon contents in Qaidam basin were higher than both Inner Mongolia and Xinjiang Tarim Basin. Furthermore, it was similar with Iran and India deserts. However, it was much lower than desert grasslands in Jilin Province. Meanwhile, we also revealed that much spatial heterogeneity has been existed in Qaidam basin. SOC contents ranged from 0.54 to 24.34 g/kg with variation coefficient of 81.14%. Therefore, SOC contents were affected by multifactor including precipitation, air temperature and soil characteristics.

4.2 Controlling process of soil chemical characteristic and climate factors on SOC in alpine deserts

Over 6% of the world's land is affected by the salinity across 100 countries mostly in arid and semiarid regions (Datta et al., 2020, Martinez-Garcia et al., 2020). Deserts soils play a vital role in regulating greenhouse gases concentrations in the atmosphere (Drahorad et al., 2013, Topa et al., 2021). Desert grasslands use may improve the status of soil organic carbon and nitrogen dynamics (Frac et al., 2020).

Nitrogen is essential to regulate the ecosystem functions and services (Ke et al., 2018). A close spatial similarity was observed between SOC contents and total nitrogen (Motaghian and Mohammadi 2012). SOC was significantly correlate with total nitrogen ($r=0.997$, $P<0.01$) in the desert of Minqin (Wang et al., 2019). In present study, deserts soil organic carbon contents were also positively driven by total nitrogen. Nowadays, average annual nitrogen deposition increased by approximately 8 kilograms per hectare between the 1980s and the 2000s (Liu et al., 2013). Deserts soil organic carbon contents would increase significantly with adding nitrogen deposition.

Soil pH can affect the content of soil organic carbon by changing plant growth and soil respiration (Chen et al., 2019, Berdugo et al., 2020). The spatial distribution of SOC is related to pH and annual precipitation in Israel deserts (Drahorad et al., 2013). Desert SOC contents were negatively correlated with soil pH (Chen et al., 2019). In addition, we also discovered that soil pH was negatively affected SOC contents in Qaidam basin. It was because there are different degrees of salinization in desert ecosystems. Furthermore, growth of vegetation was seriously restricted by high saline alkali soil, and it greatly reduced the input of soil organic carbon.

Precipitation was driven factor on SOC contents across the desert ecosystem of Hexi Corridor (Ke et al., 2018). The SOC concentrations were significantly positively correlated with annual precipitation in northern China (Chen et al., 2019). Microbial activity decreased strongly in saline soils by decreasing osmotic potential at lower water content (Datta et al., 2020). Mean annual temperature was more important to determine SOC than other abiotic factors in arid desert grasslands (Wang et al., 2014). In this study, it was indicated that deserts SOC was significantly driven by precipitation in Qaidam basin. Over the past several decades, Tibetan Plateau showed an increase in precipitation (Piao et al., 2010, Liu et al., 2018). Then, increasing regional precipitation perhaps decreased desert soils organic carbon storage in future climate scenarios.

5. Conclusion

Desert soil organic carbon contents ranged from 0.54 to 24.34 g/kg with high variation coefficient around 81.14% in Qaidam Basin. Mean and median value of SOC contents were approximate 4.86 and 3.80 g/kg.

Cluster analysis revealed that soils organic carbon contents were divided into four groups by multivariate regression trees. The largest group was around 3.32 g/kg (145 samples), when precipitation was lower than 371.5 mm, air temperature and altitude were higher than 1.49°C and 2793 m.

All TN and pH and precipitation were main driven factors on SOC by structural equation model with R^2 of 0.87. Affected coefficients were 0.99 and -0.21 and -0.16, separately ($P<0.001$). Furthermore, air temperature significantly affected soil pH ($P<0.05$). With nitrogen deposition increasing, deserts soil organic carbon contents would increase significantly in Qaidam basin.

Conflicts of interest

All authors declare no conflict of interest.

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Data availability statement

Deserts soils organic carbon and total nitrogen data in this paper would be deposited in dryad.

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