Soil Carbon and Nitrogen Content and Path Analysis under Different Land Use Patterns on the Southern Slope of the Qilian Mountains: Postprint

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Abstract

Taking four land use types on the southern slope of the Qilian Mountains as the research object, this study analyzed the contents and significant differences of soil TC (total carbon) and TN (total nitrogen) in shallow (0–20 cm) and deep (20–50 cm) layers under different land use patterns using field sampling, laboratory analysis, and one-way ANOVA, and revealed the direct and indirect effects of environmental factors on soil TC and TN through path analysis. The results showed that: (1) Environmental factors interacted with each other and jointly influenced soil carbon and nitrogen contents. Direct effects: The interaction between soil carbon and nitrogen was significant, while pH had a minor direct effect on soil carbon and nitrogen contents. Indirect effects: Soil water content (SWC) mainly exerted an indirect positive effect on shallow soil TC content through TN, whereas pH had an indirect negative effect on deep soil TC content through TN. Temperature (T) mainly exerted an indirect negative effect on shallow soil TN content through precipitation (P), while bulk density (Pb) had an indirect negative effect on deep soil TN content through TC. (2) Soil carbon and nitrogen contents exhibited a clear "surface accumulation effect". With increasing soil depth, soil carbon and nitrogen contents showed a decreasing trend. Forest land had the highest soil carbon and nitrogen contents, which were significantly higher than those of grassland and cropland ($P<0.05$), but did not differ significantly from shrubland ($P>0.05$). The soil nitrogen content in the study area was relatively high, which could provide relatively adequate nitrogen nutrients for vegetation growth in the study area. (3) Soil carbon and nitrogen contents were comprehensively influenced by both natural environment and human activities.

Full Text

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Abstract

Taking the soils under four different land use types on the southern slope of Qilian Mountain as the research object, we used field sampling, laboratory analysis, and one-way ANOVA to analyze the total carbon (TC) and total nitrogen (TN) contents in surface (0–20 cm) and deep (20–50 cm) soil layers. Path analysis was employed to reveal the direct and indirect effects of environmental factors on soil TC and TN. The results were as follows: (1) As a direct effect, the interaction between soil carbon and nitrogen was significant, but pH had little direct effect on soil carbon and nitrogen content. As an indirect effect, soil water content (SWC) had a positive effect on TC content in surface soil mainly through TN, whereas pH had an indirect negative effect on TC content in deep soil mainly through TN. Temperature (T) had an indirect negative effect on soil TN content mainly through precipitation (P), whereas bulk density (Pb) had an indirect negative effect on soil TN content mainly through TC. (2) Soil carbon and nitrogen content showed obvious "surface polymerization." The content of soil carbon and nitrogen decreased as soil depth increased. The carbon and nitrogen content of forest soil was the highest; these contents were significantly higher than those found in soil from grassland and cultivated land ($P < 0.05$) but were not significantly different from the contents in shrub soil ($P > 0.05$). The soil nitrogen content in the study area was higher than the national soil nitrogen content grading standard, which could provide sufficient nitrogen nutrient elements for the growth of vegetation in this area. (3) Soil carbon and nitrogen content was affected by the natural environment and human activities. Although this study focused on the effects of natural environmental factors on soil carbon and nitrogen content, the effects of human activities on these contents were not considered; thus, the impact of human activities should be further analyzed in future research.

Keywords: southern slope of Qilian Mountain; land use type; soil total carbon;

soil total nitrogen; path analysis

Introduction

Soil is an important component of terrestrial ecosystems, providing essential nutrient elements for plant growth. Soil carbon is the main carbon source for plants, soil animals, and microorganisms, while nitrogen is a primary element composing amino acids, and plant nitrogen is mainly absorbed from the soil [1]. Soil also serves as a crucial global carbon and nitrogen pool. Any minor changes in soil carbon and nitrogen content, whether through natural or anthropogenic disturbance, may cause changes in atmospheric CO_2 and nitrogenous greenhouse gas concentrations, thereby affecting global climate system changes, precipitation pattern distribution, and human survival [2]. Soil carbon and nitrogen content is influenced by the combined effects of natural conditions such as climate, topography, and soil physicochemical properties, as well as human activities such as land use and cultivation management [3, 4], with various interactions occurring among these factors [5].

Under the background of global change, studying and revealing the main controlling factors affecting soil carbon and nitrogen content at the regional scale is of great theoretical and practical significance for assessing the impacts of future climate change on soil carbon and nitrogen, rationally utilizing and managing land resources, and formulating regional strategies and measures to address climate change [6]. Although some scholars have studied the ecological stoichiometric characteristics of soil carbon, nitrogen, and phosphorus in the Qilian Mountains [7], the research methods employed were mostly simple correlation and multiple regression analysis. Simple correlation analysis cannot comprehensively reflect the relationships among variables, and its results are somewhat one-sided. Although multiple regression analysis can eliminate multicollinearity among variables to a certain extent, because the partial regression coefficients have units, the effects of each independent variable on the dependent variable cannot be directly compared. Path analysis, based on multiple regression, decomposes correlation coefficients into direct and indirect path coefficients. After standardization, the units are removed and the coefficients can be compared with each other, thus reflecting the degree of influence and relative importance of each independent variable on the dependent variable [8].

The Qilian Mountains constitute an important ecological security barrier and biodiversity conservation area in western China. The mountains block the southward invasion and convergence of the Tengger, Badain Jaran, Kumtag, and Qaidam Gobi deserts, preventing dry and hot storms from directly hitting the "Chinese Water Tower" of the Three-River Source region. They maintain the fragile ecological balance and sustainable economic and social development in western China, playing important roles in water conservation, soil conservation, and carbon sequestration and oxygen release [9]. The Qilian Mountains have complex terrain, obvious climate change, and diverse soil and vegetation types, with strong variability in environmental factors affecting soil carbon and nitrogen content. This study selected the southern slope of the Qilian Mountains, which has important ecological functions, and used a combination of field sampling, laboratory analysis, one-way ANOVA, and path analysis to explore the main environmental factors affecting regional carbon and nitrogen content, aiming to provide a scientific basis for vegetation management and ecological protection in this region.

1. Materials and Methods

1.1 Study Area Overview

The southern slope of the Qilian Mountains is located in the northeastern part of Qinghai Province (Fig. 1) [Figure 1: see original paper], covering most of Qilian County and Menyuan Hui Autonomous County in Haibei Tibetan Autonomous Prefecture, as well as parts of Gangcha County and Haiyan County in Haibei Tibetan Autonomous Prefecture and Tianjun County in Haixi Mongolian and Tibetan Autonomous Prefecture. The geographical location is 98°08 13 - 102°38 16 E, 37°03 17 -39°05 56 N, with a total area of approximately 2.4×10^4 km^2 and an average elevation of 3800 m [10]. The terrain is complex, dominated by mountains with high elevations in the northwest and low elevations in the southeast. Affected by climate and topography, the study area shows obvious vertical differentiation in soil and vegetation. Soil types include mountain forest soil, gray-cinnamon soil, chestnut soil, black soil, alpine steppe soil, meadow soil, and cold desert soil. The forest is dominated by cold-temperate coniferous forests, mainly including coniferous forests with *Picea crassifolia* as the main constructive species, coniferous mixed forests composed of *Picea crassifolia* and *Sabina przewalskii*, *Sabina przewalskii* sparse forests, broad-leaved forests composed of *Populus davidiana*, *Betula platyphylla*, and white birch, as well as coniferous-broad-leaved mixed forests. Shrub types mainly include *Potentilla fruticosa*, willow, and *Caragana jubata*. Herbaceous plants are mainly Gramineae, *Artemisia*, *Carex*, and *Artemisia sphaerocephala* [11]. Cultivated land mainly includes highland barley and potatoes.

1.2 Sample Collection and Measurement

Based on the topography, landform, elevation, and land use status of the study area, combined with field surveys, soil samples were collected in July 2019 under four land use patterns: forest land, shrubland, grassland, and cultivated land. The geographic coordinates of each sampling point were obtained using the Ovital Interactive Map. A standard plot of 20 m × 20 m was set up for each land use pattern, and five 1 m × 1 m standard quadrats were arranged in each plot using an S-shaped pattern. Soil samples were collected layer by layer from top to bottom using a soil drill with a diameter of 10 cm at depths of 0–20 cm and 20–50 cm. Five sampling points were mixed into one soil sample, plant roots and residues were removed, and the samples were placed in labeled self-sealing bags and weighed. A total of 48 soil samples were collected. The soil samples were brought back to the laboratory and air-dried in a ventilated, cool, and dry indoor environment, then sieved and ground for determination of relevant indicators. Soil water content was determined using the drying method, bulk density was determined using the ring knife method, and pH was determined using the extraction electrode method (soil:water = 2.5:1.0) [12]. Soil particle size was determined using a Master-sizer 2000 laser particle size analyzer. Soil carbon and nitrogen contents were determined using a vario ISOTOPE cube elemental analyzer produced by Elementar Company.

1.3 Data Sources and Processing

Meteorological data were obtained from the China Meteorological Data Sharing Network (http://cdc.cma.gov.cn). The professional meteorological interpolation software Anusplin was used to interpolate the average temperature and precipitation during the growing season for 12 meteorological stations within and around the study area. Vegetation index products were derived from MODIS satellite data (https://ladsweb.nascom.nasa.gov/). The "Extract Multi Values to Points" tool in ArcGIS was used to extract corresponding temperature, precipitation, and NDVI data based on the latitude and longitude of sampling points. Data processing and statistical analysis were completed in SPSS 20 and Excel 2010 software. Stepwise regression analysis was used to establish multiple regression equations for environmental factors and TC and TN contents. Selected environmental factors included temperature (T), elevation (Elv), precipitation (P), slope (Slp), soil bulk density (Pb), soil water content (SWC), normalized difference vegetation index (NDVI), clay, silt, and sand. Based on the regression analysis results, path analysis was performed on significant factors to compare the degree of influence and relative importance of each factor on TC and TN contents. One-way ANOVA was used for significance testing, and the Duncan method was used for multiple comparisons. Pearson method was used for simple correlation analysis, and Origin software was used for plotting. All experimental data are expressed as mean ± standard deviation.

2. Results

2.1 Soil TC and TN Contents and Significance Analysis under Different Land Use Patterns

Calculating soil carbon and nitrogen content in a single profile using layer thickness as a weight can reduce estimation errors caused by differences in soil carbon and nitrogen at different depths [13]. In this study, the surface soil carbon and nitrogen content was the weighted average of 0–20 cm, and the deep soil carbon and nitrogen content was the weighted average of 20–50 cm. As shown in Table 1 , among the four land use types, the difference in TC content in surface soil was greater than that in deep soil. The difference in TC content between forest land and cultivated land was the largest, at 45.15 $g \cdot kg^{-1}$, and the difference in TN content between forest land and cultivated land was the largest, at 2.94 $g \cdot kg^{-1}$. The TC content of surface soil was about 1.5 times that of deep soil. Forest land had the highest TC and TN contents, which were significantly higher than those of grassland and cultivated land ($P < 0.05$) but not significantly different from shrubland ($P > 0.05$). With increasing soil depth, TC and TN contents under all four land use types showed a decreasing trend. Among them, grassland showed the largest decrease in TC and TN contents between surface and deep soil, with deep soil TC and TN contents decreasing by 44.76% and 46.01% compared with surface soil, respectively. Cultivated land showed the smallest difference between surface and deep soil TC and TN contents, decreasing by 5.11% and 3.34%, respectively. Except for cultivated land, the TC and TN contents in surface soil under the other three land use types were significantly higher than those in deep soil ($P < 0.05$). Overall, the order of surface soil TC and TN contents was: forest land > shrubland > grassland > cultivated land. The order of deep soil TC and TN contents was slightly different: forest land > grassland > shrubland > cultivated land. According to the national soil nitrogen content grading standard, >2 $g \cdot kg^{-1}$ indicates an excellent state [14], indicating that the soil nitrogen content in the study area is high and can provide sufficient nitrogen nutrient elements for vegetation growth.

2.2 Stepwise Regression Analysis of Soil TC and TN with Environmental Factors

Multiple regression equations were established between environmental factors and TC and TN contents in surface and deep soil through stepwise regression analysis:

Surface soil (0-20 cm): TC = 84.09 + 9.15TN - 8.14pH + 0.26SWC
TN = -16.33 + 0.07TC + 0.08P + 0.51T + 0.36pH

Deep soil (20-50 cm): TC = 70.33 + 9.69TN - 9.50pH
TN = -0.91 + 0.06TC - 1.47Pb + 0.02Slp + 0.43pH

The regression equations showed that TN, pH, and SWC had significant effects on TC content in surface soil ($P < 0.05$). TC, P, T, and pH had significant effects on TN content in surface soil ($P < 0.05$). TN and pH had significant effects on TC content in deep soil ($P < 0.05$). TC, Pb, Slp, and pH had significant effects on TN content in deep soil ($P < 0.05$). Other environmental factors were not significant and were eliminated in the stepwise regression. Due to interactions among environmental factors, there may be collinearity in regression analysis. Therefore, variance inflation factor (VIF) and tolerance (Tol) were used for multicollinearity diagnosis. When VIF > 10 or Tol < 0.1, serious multicollinearity exists among independent variables. Table 2 shows that VIF < 10 and Tol > 0.1, indicating no multicollinearity problems among environmental factors.

2.3 Path Analysis of Environmental Factors' Effects on Soil TC and TN Content

Stepwise regression analysis cannot intuitively reflect the contribution of each environmental factor to soil carbon and nitrogen content. However, by calculating path coefficients using standardized regression coefficients and decomposing correlation coefficients into the algebraic sum of direct and indirect path coefficients, the effects of each environmental factor on soil carbon and nitrogen content can be more intuitively reflected [15]. Path analysis was performed on significant environmental factors affecting TC and TN contents, with path coefficients calculated according to reference [16]. The results are shown in Tables 3 and 4 [TABLE:3, TABLE:4].

2.3.1 Path Analysis of Environmental Factors' Effects on TC Content

Table 3 shows that among the significant environmental factors affecting TC content in surface and deep soil, TN had the largest direct path coefficient, indicating that TN had the largest direct effect on TC content, showing a positive effect. pH had a smaller direct effect on TC content, showing a negative effect. For surface soil, the environmental factor with the largest indirect path coefficient for TC content was SWC, which had an indirect positive effect on surface soil TC content mainly through TN, followed by pH, which had an indirect negative effect on surface soil TC content mainly through TN. For deep soil, the environmental factor with the largest direct path coefficient was TN, which had an indirect negative effect on deep soil TC content. The direct path coefficients of TN and pH were larger than their indirect path coefficients, indicating that their contributions to TC content were mainly direct effects. The indirect path coefficient of SWC was larger than its direct path coefficient, indicating that its main contribution to TC content was indirect effects through influencing other factors.

2.3.2 Path Analysis of Environmental Factors' Effects on TN Content

Table 4 shows that among the significant environmental factors affecting TN content in surface soil, TC and pH had relatively large direct effects, with direct path coefficients above 0.3 and showing positive effects, while T had the smallest effect. For deep soil, the significant environmental factors affecting TN content were TC, Pb, Slp, and pH, with TC having a large direct effect and Pb having a small direct effect. Among all environmental factors, the factor with the largest indirect path coefficient for surface soil TN content was pH, which had the largest indirect effect on surface soil TN content mainly through TC. The factor with the smallest indirect effect was T. The factor with the largest indirect path coefficient for deep soil TN content was Pb, which had an indirect negative effect on deep soil TN content mainly through TC, followed by pH. The factor with the smallest indirect effect was Slp. The direct path coefficients of TC, T, and pH were larger than their indirect path coefficients, indicating that the main contributions of these environmental factors to TN content were direct effects. The indirect path coefficient of Pb was larger than its direct path coefficient, indicating that its main contribution to TN content was indirect effects through influencing other factors.

3. Discussion

3.1 Effects of Land Use Patterns on Soil Carbon and Nitrogen Content

The results of this study showed that forest and shrubland soils in the study area had relatively high TC and TN contents, while grassland and cultivated land had relatively low contents. These differences may be related to climate conditions, vegetation types, litter stock, root distribution, human disturbance, and soil management practices [17]. Surface litter is one of the most important sources of soil organic carbon [18]. Compared with shrubland, grassland, and cultivated land, forest land has more surface litter and is distributed at higher altitudes. As altitude increases, temperature gradually decreases while precipitation increases within a certain range. The low-temperature and humid environment makes litter difficult to decompose and slows the mineralization of soil organic matter, leading to carbon accumulation [19]. In addition, forest land has deeper roots, more understory litter, and less human disturbance, resulting in more soil organic matter accumulation and less decomposition. Cultivated land has less carbon content because it is strongly affected by human management activities such as tillage, and the traditional farmland management measures and single crop production model cause serious loss of soil organic matter components, thereby affecting the accumulation of soil organic matter and storage of organic carbon [20]. Differences in soil carbon content under different land use patterns are also related to root growth and distribution. Roots are the only way to directly transfer crop photosynthate to the underground [21], and the decomposition of a large number of dead roots can provide rich nutrients for the soil. The roots of forest land and shrubland are deeper than those of grassland and cultivated land, resulting in higher soil carbon content in forest land and shrubland.

The study of soil carbon and nitrogen content in surface and deep soil under different land use patterns on the southern slope of Qilian Mountains showed that soil carbon and nitrogen content was greater in surface soil than in deep soil, showing obvious "surface polymerization." This is consistent with the research of Niu et al. [22] on the characteristics of shallow soil carbon content in *Picea crassifolia* forest in Qilian Mountains. This is mainly because organic carbon formed by the decomposition of aboveground litter and underground plant roots first enters the soil surface, making surface soil carbon content significantly higher than deep soil content. In addition, as soil depth increases, plant roots in the soil become fewer and humus content decreases significantly compared with the surface, so soil carbon content shows a decreasing trend with increasing soil depth [23]. Soil nitrogen content also showed surface > deep layer, mainly because soil nitrogen content is affected by rainfall, animal and plant residues, litter, plant roots, and microbial decomposition. Nutrient elements formed by the decomposition of surface litter and underground plant roots first enter the soil surface, making surface soil nitrogen content higher than deep soil content [24].

3.2 Effects of Environmental Factors on Soil Carbon and Nitrogen Content

There is a high degree of synergy between soil carbon and nitrogen [25]. In this study, surface and deep soil carbon and nitrogen were positively correlated, which is consistent with the research results of Zhang et al. [26]. This is because when plant residues enter the soil and undergo decomposition, carbon becomes CO_2 while nitrogen becomes nitrate that is leached or absorbed by plants. The C:N ratio in the soil will become roughly the same, and when relative equilibrium is reached, soil nitrogen content roughly determines soil carbon content [27].

The results of this study showed that TN, temperature, precipitation, pH, and bulk density are important factors affecting soil carbon and nitrogen. Temperature and precipitation are important factors affecting surface soil TN content. Temperature is negatively correlated with surface soil TN content, while precipitation is positively correlated with surface soil TN content. This is because temperature mainly controls soil respiration flux, plant root growth, soil animal activity, soil microbial activity, and the decomposition rate of soil nutrients, indirectly affecting soil TN content. Increased temperature can promote plant nitrogen absorption and input to a certain extent, promote nitrogen deposition and mineralization, and precipitation can effectively improve the water environment of plant roots and soil microorganisms in surface soil. Soil moisture regulates soil respiration intensity by affecting plant root growth, microbial activity, soil porosity, and gas diffusion. Increased precipitation is beneficial to the storage and accumulation of soil nitrogen to a certain extent [28]. pH is negatively correlated with surface and deep soil carbon and nitrogen because pH significantly affects the ability of soil microorganisms to fix and accumulate carbon and nitrogen by influencing their activities [29]. Soil microorganisms generally have the highest activity in the neutral pH range of 6-8, and both overly acidic and overly alkaline conditions severely inhibit soil microbial activity, thereby affecting the transformation and supply of nitrogen and other nutrients. Soil bulk density is an important factor affecting deep soil TN content and is negatively correlated with deep TN content, which is consistent with the research results of Miao et al. [30]. This is because soil bulk density affects soil microbial activity and the material cycle of soil nutrients by influencing soil porosity, aeration, and water-heat conditions, thereby affecting soil nitrogen content.

4. Conclusion

This study took the southern slope of Qilian Mountains as the research area and investigated the soil carbon and nitrogen contents under four different land use patterns and their relationships with environmental factors. The main conclusions are as follows:

1. There are obvious interactions among environmental factors that jointly affect soil carbon and nitrogen content. TN has the largest direct effect on

TC content at different soil depths, while pH has a relatively small direct effect on TC content. SWC has an indirect positive effect on surface soil TC content mainly through TN, while pH has an indirect negative effect on deep soil TC content mainly through TN. Temperature has an indirect negative effect on soil TN content mainly through precipitation, while bulk density has an indirect negative effect on soil TN content mainly through TC.

2. Soil carbon and nitrogen content shows obvious "surface polymerization." With increasing soil depth, TC and TN contents show a decreasing trend. Forest soil has the highest carbon and nitrogen content, which is significantly higher than that of grassland and cultivated land ($P < 0.05$) but not significantly different from shrubland ($P > 0.05$). The soil nitrogen content in the study area is relatively high and can provide sufficient nitrogen nutrient elements for vegetation growth. Vegetation management and protection should be strengthened to ensure the balance and cycling of regional soil nutrient elements.

3. Soil carbon and nitrogen content is affected by the comprehensive influence of structural factors such as climate and soil physicochemical properties, as well as stochastic factors such as human activities. This study focused on the effects of natural environmental factors on soil carbon and nitrogen content but did not consider the effects of human activity factors, which should be further analyzed in depth in future research.

References

[1] Spain A V. Influence of environmental conditions and some soil chemical properties on the carbon and nitrogen contents of some tropical Australian rainforest soils[J]. Australian Journal of Soil Research, 1990, 28(6): 825-839.

[2] Homann P S, Kapchinske J S, Boyce A. Relations of mineral soil C and N to climate and texture: regional differences within the conterminous USA[J]. Biogeochemistry, 2007, 85(3): 303-316.

[3] Sollins P, Homann P, Caldwell B. Stabilization and destabilization of soil organic matter: Mechanisms and controls[J]. Geoderma, 1996, 74: 65-105.

[4] Wang Shufang, Wang Xiaoke, Ouyang Zhiyun. Path analysis on environmental factors controlling soil organic carbon and total nitrogen contents in the upstream watershed of Miyun Reservoir, North China[J]. Ecology and Environmental Sciences, 2014, 23(8): 1378-1383.

[5] Zhang Guangde, Zhao Chuanyan, Rong Zhanlei, et al. Ecological stoichiometry of soils with different vegetation types in the middle part of the Qilian Mountains[J]. Journal of Lanzhou University (Natural Sciences Edition), 2019, 55(4): 533-540.

[6] Gao Zhiren. Quantitative Genetics[M]. Chengdu: Sichuan University Press,

1986: 198-226.

[7] Zhao Weijun, Liu Xiande, Jin Ming, et al. Ecological stoichiometric characteristics of carbon, nitrogen and phosphorus in *Picea crassifolia* litter soil system of forest in the Qilian Mountains[J]. Acta Pedologica Sinica, 2016, 53(2): 477-489.

[8] Liu Fang, Cao Guangchao, Cao Shengkui, et al. Hydrogen and oxygen isotope characteristics of water bodies on the southern slope of Qilian Mountains[J]. Arid Zone Research, 2020, 37(5): 1116-1123.

[9] Duan Zhonghua, Qiao Youming, Quan Xiaolong, et al. Analysis of nitrogen and carbon composition and stable isotope characteristics and physicochemical properties of wetland and grassland soil in source region of the Yellow River[J]. Journal of Soil and Water Conservation, 2015, 29(4): 247-252, 315.

[10] Cao Lihua, Liu Heman, Zhao Shiwei. Distribution of soil organic carbon and its relationship with soil physical and chemical properties on degraded alpine meadows[J]. Pratacultural Science, 2011, 28(8): 1411-1415.

[11] Cao Shengkui, Chen Kelong, Cao Guangchao, et al. Influence of *Kobresia* grassland degradation on the soil carbon density of the pygmaea meadow in the Qinghai Lake Basin[J]. Research of Soil and Water Conservation, 2014, 21(1): 71-75.

[12] Bao Shidan. Soil Agrochemical Analysis[M]. 3rd ed. Beijing: China Agriculture Press, 2000.

[13] Jobbágy Esteban G, Jackson, Robert B. The vertical distribution of soil organic carbon and it' s relation to climate and vegetation[J]. Ecological Applications, 2000, 10(2): 423-436.

[14] Zhang Yangyang. Study on Contents and Spatial Distribution Characteristics of Soil Carbon, Nitrogen and Phosphorus in Bailong River Basin[D]. Lanzhou: Lanzhou University, 2017.

[15] Song Xiaoyuan, Zhu Zhongyuan, Liu Yanwei, et al. Application of path analysis in stepwise linear regression SPSS[J]. Arid Zone Research, 2016, 33(1): 108-113.

[16] Wang Yanlong, Wang Xiaoli, Ma Yushou. Effect of slope aspect on vegetation growth and soil nutrient characteristics of alpine grassland in the source region of Yangtze River[J]. Pratacultural Science, 2018, 35(10): 2336-2346.

[17] Zhao Zhenzhen, Zhang Xiangfeng, Dong Shikui, et al. Soil organic carbon and total nitrogen stocks in alpine ecosystems of Altun Mountain National Nature Reserve in dry China[J]. Environmental Monitoring and Assessment, 2019, 191(1): 40.

[18] Kong Junqia, Du Zeyu, Yang Rong, et al. Evolutionary characteristics of soil organic carbon storage in soil plough layer under a cropland reclamation process in desert oasis[J]. Chinese Journal of Applied Ecology, 2019, 30(1): 180-188.

[19] Cui Jing, Chen Yunming, Huang Jiajian, et al. Soil *Caragana microphylla* carbon sequestration characteristics of plantations and influencing factor in loess hilly semiarid region[J]. Chinese Journal of Eco-Agriculture, 2012, 20(9): 1197-1203.

[20] Bai Junhong, Deng Wei, Zhu Yanming, et al. Spatial distribution characteristics and ecological effects of carbon and nitrogen of soil in Huolin River catchment wetland[J]. Chinese Journal of Applied Ecology, 2003, 14(9): 1494-1498.

[21] He Jienan, Xie Jituo, Xiao Yifeng, et al. Studies of soil organic carbon and its spatial distribution in mountain Mangshan[J]. Journal of Central South University of Forestry & Technology, 2014, 34(4): 72-76.

[22] Niu Yun, Liu Xiande, Zhao Weijun, et al. Characteristics and interrelation of shallow soil organic and total nitrogen in *Picea crassifolia* forest in the Qilian Mountain, Gansu, China[J]. Journal of Desert Research, 2014, 34(2): 371-377.

[23] Yao Tuo, Long Ruijun. Dynamics of soil microbial population under disturbance in Tianzhu Alpine grassland[J]. Acta Prataculturae Sinica, 2006, 15(2): 93-99.

[24] Zhang Yaoyao. Spatial Distribution Characteristics and Influencing Factors of Soil Organic Carbon and Total Nitrogen in Gannan Pastoral Area[D]. Lanzhou: Lanzhou University, 2019.

[25] Gou Zhaojun. Study on Distribution Characteristics and Influencing Factors of Soil Carbon, Nitrogen, Phosphorus and pH Value in Alpine Grassland of Upper Yellow River[D]. Xining: Qinghai Normal University, 2019.

[26] Zhang Shaofeng. Study on the Carbon and Nitrogen Characteristics of Community and Soil for *Leymus chinensis* Grassland under Different Utilization Ways in Xilingol Steppe[D]. Hohhot: Inner Mongolia University, 2018.

[27] Huang Jun, Ma Ruifu, Cui Shoubin, et al. Soil carbon, nitrogen, and phosphorus concentrations and stoichiometry under different wetland restoration methods in Qixing River[J/OL]. Journal of Shanxi University (Natural Science Edition): 1-16[2020-10-11].

[28] Zhou Yanxiang, Lyu Maokui, Xie Jinsheng, et al. Sources, characteristics and stability of organic carbon in deep soil[J]. Journal of Subtropical Resources and Environment, 2013, 8(1): 48-55.

[29] Hu Yawei, Sun Ruoxiu, Shen Mingshuang, et al. Effects of land use types on the stoichiometric characteristics of soil C:N:P and the physical and chemical properties of soil[J/OL]. Arid Zone Research, 1-12[2021-06-23]. http://kns.cnki.net/kcms/detail/65.1095.X.20210610.1309.003.html.

[30] Miao Juan, Zhou Chuanyan, Li Shijie, et al. Accumulation of soil organic carbon and total nitrogen in *Pinus yunnanensis* forests at different age stages[J]. Chinese Journal of Applied Ecology, 2014, 25(3): 625-631.

[31] Wang Weixia, Yang Guang, Wang Zhenxi. Effects of regeneration patterns on soil carbon and nitrogen in *Picea schrenkiana* tianshanica[J]. Xinjiang Agricultural Sciences, 2020, 57(8): 1474-1483.

[32] Zhu Fengwu, Xu Caiyao, Pu Lijie, et al. Effects of reclamation activity on soil C, N and P contents and the stoichiometric characteristics of coastal wetland in Northern Jiangsu Province[J]. China Land Science, 2017, 31(12): 77-83.

Note: Figure translations are in progress. See original paper for figures.