Soil fertility evaluation and spatial distribution of grassland in Qilian mountain nature reserve-Tibetan Plateau

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Abstract: The study assessed the overall soil characteristics of Qilian mountain grassland and rated soil nutrient status with [redacted] China's second national soil census grading standard. The Nemerow index method was used to evaluate the soil fertility of different grassland types. GIS was used to analyse the soil nutrients spatial distribution and provide a data basis for the grassland's ecological protection and restoration. The authors graded the content of soil organic matter (SOM), total N, and available K at level 2 (high) or above for most regions, while available soil-P was graded at level 4. While the soil bulk density, total porosity, and pH were 0.77-1.32 g cm^{-3}, 35.36-58.83%, and 7.63-8.54, respectively. The soil comprehensive fertility index was in the ranking order of Temperate steppe(TS) >Alpine meadow (AM) > Alpine steppe(AS) >Upland meadow (UM) >Alpine desert (AD) > Lowland meadow (LM) > Temperate Desert Steppe (TDS) > Temperate Desert (TD) . The areas with high, medium, and low soil fertility accounted for 63.19%, 34.24%, and 2.57% of the total grassland area of Qilian mountain. Soil fertility at different grassland types had various main limiting factors. For instance, the pH, total-N, and SOM were the main factors limiting soil fertility in LM, and pH and available P were the main factors limiting soil fertility in UM, AM, TS and AS. The grassland soil fertility of Qilian mountain was generally at the mid-upper level. The main limiting factors found in the different types of grasslands and spatial distribution, the typical grasslands and meadows may need to apply acidic phosphate fertilizers, and desert grasslands to apply compound fertilizers of nitrogen and phosphorus to improve comprehensive soil fertility to improve grassland productivity.

Keywords: grasslands; soil fertility; Qilian natural reserve; spatial distribution;

Introduction

The Qilian mountain natural reserve is one of the most sensitive regions under global warming and an important ecological security barrier in northwestern of China (Wang et al., 2001). Grassland ecosystem is the largest ecological system in Qilian mountain natural reserve, which accounts for 74.3% of the total area and plays an important role in maintaining biodiversity, water conservation and ecological balance of the natural reserve (Li et al., 2019). In last few decades climate change, human activities and mismanagement have severely damaged the Qilian mountain grassland ecosystem. Understanding the current status of grassland soil in Qilian mountain is of great significance to the health and sustainable development of grassland ecosystems. There are many types of grasslands in Qilian mountain. Due to differences in terrain, rainfall and temperature, the distribution of the same type of grassland is very patchy and has discontinuities and irregularities. Previous studies found that different grassland types have large differences in soil nutrients due to the differences in vegetation types and utilization methods (grazing, water conservation and sand fixation) (Fayiah et al., 2019; Chen et al., 2020).

Soil fertility has a directly impact on the health of grasslands and is also influenced by grassland vegetation (Hao et al., 2020). Without human disturbance, the growth and distribution of grassland vegetation is strongly affected by soil fertility apart from climate (Wang et al., 2016; Harpole et al., 2007). Soil fertility not only affects the growth of grassland vegetation, but also affects the grassland ecosystem health (Ma et al., 2019). Therefore, good understanding and objective evaluation of soil fertility

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characteristic is of great significance to restoration regional vegetation, and improvement of fragile grassland ecosystem (Su et al., 2019; Jin et al., 2018).

Grassland soil fertility plays a key role in supporting grassland ecosystem services (Clanet, 1980; Hu et al.,2018; Qu et al.,2016). Soil organic matter, available nitrogen, available phosphorus, available potassium, soil bulk density and pH are important components of soil fertility, while their content directly affect grassland vegetation productivity (Wuest, 2015; Li et al., 2014). Many methods have been used for soil fertility evaluation, including Nemerow index method (Hua et al., 2018; Shahab et al., 2013), AHP (Keshavarzi et al., 2020; Sousa et al., 2012), correlation coefficient method, principal component analysis, etc. Among those evaluation methods, Nemerow index method has been well recognized due to it can avoid the influence of subjective factors, which could highlight the influence of the worst factor of soil attribute factors on soil fertility (Bao et al., 2012). Also Nemerow comprehensive index method reflects the law of the limiting factor of plant growth in ecology, which can improve the credibility of the evaluation results (An et al., 2015; Zhou et al., 2017). Comprehensive evaluation of soil fertility combining with geographic information system (GIS) has been widely used to assess spatial distribution characteristics of soil nutrients, which is helpful to explore the relationship between soil nutrients and environmental factors (Wang et al., 2007; Peng et al., 2013; Nie et al., 2016; Brevik et al. 2016; Miller et al. 2016).

Many studies have been carried out on the soil of degraded grassland in Qilian mountain (Cheng et al., 2019; Wang et al., 2018; Chen et al., 2016). However; there are few studies on grassland soil fertility and its spatial distribution characteristics in Qilian mountain. Therefore, the aims of this study were to investigate the soil of different type grasslands in Qilian mountain natural reserve, 2) to analyze the distribution characteristics of soil fertility index, and 3) to determine the limiting factors for grassland soil fertility in Qilian mountain nature reserve, which can help to provide scientific insight for improving grassland ecological services. (Check the numeration)

1 Materials and methods

1.1 Study area

The study sites were located in the Qilian mountain nature reserve in Gansu province, China (94°10′-103°04′E, 35°50′-39°19′N). From southeast to northwest at horizontal direction, there are four vegetation zones in the following order of forest, shrub, grassland and desert. At vertical direction, from low to high altitude (3000-5564 mm), there are three vegetation belts: grassland belt, forest belt and alpine meadow grassland belt. The main types of soil are mountain gray cinnamon soil, subalpine meadow soil, alpine meadow soil and alpine cold desert soil. The precipitation varies from 100 to 500 mm, mostly occurring during June to September. The average annual temperature is from -0.6 to 2.0℃; the average annual relative humidity is from 20% to 70%; the annual evaporation is about 1200-1400 mm; and the frost-free period is about 90-120 days (http://www.qilianshan.com.cn).

1.2 Sites selection and Sample collection

This study sites were mainly located on the Qilian mountain natural reserve in Gansu province, China. The grassland types were Temperate steppe (TS), Alpine meadow (AM), Alpine steppe (AS), Upland meadow (UM), Alpine desert (AD), Temperate desert steppe (TDS), Lowland meadow (LM), Temperate desert (TD) (Table 1) (NY/T 2997-2016, 2016). (CONSISTENCE in the use of capitals)

The sampling time of this study was from July 23 to August 5, 2019, when the plants were in full bloom. The central points (table 1) of the typical distribution area of the above 8 types of grasslands (AM, TS, LM, AS, UM, TDS, AD and TD) were selected as the sampling sites. A 60-meter sample line was randomly set for each sample site and the sample spots were set for every 20-meter intervals. Four soil samples were taken at each sampling sites using soil drill (an auger drill) at a depth of 0 - 30 cm, respectively. The four soil samples were mixed to compose one sample. The samples were put into a sample bag and taken back to a laboratory for air-drying for further test. Three soil samples were taken at each sample site. Meanwhile, a 100 cm^3 soil clod was taken using ring knife method at each soil layer to measure soil bulk density and total porosity.

1.3 Sample analyses

Soil bulk density was determined by the [redacted] core method (Dong et al., 2012). Total porosity was determined by [redacted] water immersion weighing method (Soil Physics institute, 1978). Soil samples were air-dried at room temperature, and visible roots and other debris in the soil were removed. Each soil sample was sieved through a 2-mm sieve. Soil organic matter was determined by the Walkley–Black method (Nelson and Sommers, 1996). As for the measurement of total soil N was determined using a small-scale Kjeldahl digestion procedure (Nelson and Sommers, 1996). Briefly, a small amount of dried soil (passing 0.25 mm sieves) mixed with H_2SO_4, $CuSO_4{\cdot}H_2O$ and K_2SO 4 was heated and then made up with ammonium-free distilled water. The solution was mixed with 4 ml 40% NaOH and distilled using a Kjeldahl apparatus to release NH_3 to determine N content. Available P was extracted with HF-HNO_3-$HClO_4$ or sodium bicarbonate, ~~respectively~~, and then determined by the molybdenum blue method. Available K were extracted with HF-HNO_3-$HClO_4$ and ammonium acetate, respectively, and then determined by flame photometry.

1.4 Evaluation of soil fertility

1.4.1 Evaluation of individual indicators of soil fertility

This study used the China second soil census standard (National Geographic Resource Science SubCenter, http://gre.geodata.cn) (Table 2) to rank the grassland soil organic matter, total N , (latter on appears available P. Should be included here ?) available N, pH, bulk density and total porosity indicators of Qilian mountain grassland, and to compare the differences between different grassland types (Zhou et al., 2017).

1.4.2 Comprehensive soil fertility evaluation

The improved Nemerow index method was used to comprehensively evaluate the soil fertility quality of Qilian mountain (Zhou et al., 2017; Zhou et al., 2018). According to the grading standards of soil properties in the China second soil census standard (Table 3), the selected index parameters were standardized to eliminate the dimensional difference between the parameters. The standardized treatment methods are as follows:

When the attribute value belongs to the level of low, $c_i \le x_a$, $F_i = c_i / x_a \quad (F_i \le 1)$ (1)

When the attribute value belongs to the level of upper, $x_a < c_i \le x_c$, $F_i = 1 + (c_i - x_a) / (x_c - x_a) \quad (1 < F_i \le 2)$ (2)

When the attribute value belongs to the level of high, $x_c < c_i \leq x_p$, $F_i = 2 + (c_i - x_c)/(x_p - x_c)$ $(2 < F_i \leq 3)$ (3)

When the attribute value belongs to the level of very high, $c_i > x$, $F_i = 3$ (4)

In the above formulas, F_i is the attribute division coefficient, c_i is the measured value of the attribute, and x_a, x_c, and x_p are the classification indexes.

The improved Nemerow index method was then used to comprehensively evaluate the grassland soil fertility in Qilian mountain. The revised Nemerow formula is as follows:

$$F = \sqrt{\frac{Fi^2 + Fimin^2}{2}} \cdot \left(\frac{n-1}{n}\right)$$

Where F is the soil comprehensive fertility index, F_i is the average value of each sub-fertility index, F_{imin} is the minimum value of each sub-fertility index, and n is the number of participating indicators.

1.5 Soil comprehensive fertility index spatial distribution

Analysis method based on multiple regression and residues (AMMRR) had been widely used in many studies for grassland spatial interpolation (Liu et al., 2012; Guo et al., 2011). This method is more accurate than many other interpolating methods and can also effectively avoids systematic errors(Liu et al., 2012; Guo et al., 2011). In this paper, based on the comprehensive fertility index determined by the improved Nemerow index method, and the ArcGIS10.2.2 (Mărgărit M. Nistor, 2016 Wrong form to cite Nistor, M.M: see References) was used to conduct the spatial analyses including extracting the center points of different grassland types (Figure 1), assigning values for grassland types, performing AMMRR interpolation, and drawing the Qilian mountain grassland soil fertility index spatial distribution. The comprehensive fertility index was divided into low (<1.50), medium (1.50-2.00), and high (> 2.00).

1.6 Statistical analyses

Statistical analyses were conducted using SPSS (version 19.0 SPSS Inc., Chicago, IL, USA). All results were presented as mean and standard deviations. One-way ANOVA and least significant difference (LSD) tests were declared at $P < 0.05$.

2 Results

2.1 Characteristics of grassland soil fertility indexes

The soil bulk density of Qilian mountain grassland was 0.77-1.32 g cm^{-3}, with an average value of 1.01 g cm^{-3} and a CV of 17.88% (Table 4). The total porosity was 35.36-58.83%, with an average value of 48.25% and a CV of 16.38%. The pH was 7.63-8.54, with an average value of 8.07 and a CV of 4.71%. The total N was 0.63-4.97 g kg^{-1}, with an average value of 2.38 g kg^{-1} and a CV of 75.49%. The available P was (see comment above) 6.79-24.27 mg kg^{-1}, with an average value of 12.81 mg kg^{-1} and a CV of 43.09%. The available K was 0.21-1.06 g kg^{-1}, with an average value of 0.40 g kg^{-1} and a CV of 68.00%. The soil organic matter was 4.99-131.52 g kg^{-1}, with an average value of 51.23 g kg^{-1} and a CV of 95.32%.

2.2 Soil physical and chemical features in different type grasslands

The soil fertility index for different type grasslands are shown in Table 5. There was significant difference ($P < 0.05$) between all other soil fertility indexes of different grassland types. Soil bulk density was in a ranking order of desert type > meadow type > steppe type, or AM > TS > LM > AS > UM > TDS > AD > TD. The total porosity was in a ranking order of TS > AS > AM > UM > TDS > LM >

AD > TD. The pH was in a ranking order of TD > LM > TDS > UM > AD > AS> AM > TS. Total N was in a ranking order of AM > TS > AS > UM > AD > TDS > LM > TD. The soil organic matter was in ranking order of TS > AM > AS > UM > AD > TDS > LM > TD. The available P was in a ranking order of LM > TS > AM > AS > UM > TD > TDS > AD. The available K was in a ranking of LM > UM > AS > TD >TS > AM > AD > TDS.

2.3 Soil physical and chemical spatial distribution

The soil physical and chemical spatial distributions were showed in Fig.2. Soil bulk density in most areas was 0.75-0.94 g cm^{-3}. Total porosity in most areas was 50-60%. pH in most areas was 8-9. The SOM in most areas was 30-134 g kg^{-1}. The total N in most areas was 2.0-5.0 g kg^{-1}. The available P in most areas was 10-20 mg kg^{-1}. The Available K in most areas was 0.3-1.5 g kg^{-1}.

2.4 Soil comprehensive fertility index

The soil comprehensive fertility index of different type grasslands ranged from 1.01 to 2.24 (Table 6). The soil comprehensive fertility index was significantly higher in AM, UM, AS and TS than in AD, significantly higher in AD than in LM and TDS, and significantly higher in TDS than in TD, but no significant differences were found among others. The soil comprehensive fertility index was in a ranking order of TS > AM > AS > UM > AD >LM > TDS > TD.

The soil fertility of Qilian mountain grassland was at a moderate or high level (Fig.3). In terms of spatial distribution, the soil comprehensive fertility index was higher in eastern and western of Qilian mountain, and the soil fertility in the central region was moderate. There are only a few areas where the soil fertility of the grassland was low, distributed in the marginal regions of the western and central regions. The areas with high, medium and low soil fertility accounted for 63.19%, 34.24% and 2.57% of the total grassland area of Qilian mountain.

2.5 limiting factors for grassland soil comprehensive fertility

The different type grasslands soil fertility had different major limiting factors (Table 6). For example, the pH, total N and SOM were the main factors limiting soil fertility in LM, and pH and available P were the main factors limiting soil fertility in UM, AM, TS and AS. The Soil bulk density, pH, total N, SOM and available P were the main factors limiting soil fertility in TD and TDS. Soil bulk density and available P were the main factors limiting soil fertility in AD. The limiting factors for grassland soil comprehensive fertility of Qilian mountain grassland was showed in Fig.3.

3 Discuss

Soil organic matter content is closely related to soil fertility and soil health. The available forms of nitrogen, phosphorus, and potassium provide essential nutrients for plant growth and development, and are the main components of soil nutrients (Zhang et al.,2013; Zhou et al., 2016). The content of SOM and available K were graded as level 2 (high) or above for Qilian mountain grasslands according to the classification of China second soil census standards(National Geographic Resource Science SubCenter, http://gre.geodata.cn). Available P was graded as level 4 with the contents of 6.79-24.27 mg kg^{-1}. Our studies difference between the maximum value and the minimum value of each fertility index was quite large, there was a background difference does not have a clear meaning (check this sentence). This finding was similar to the results obtained by Cui et al. (2010) and Zhou et al. (2017) for urban green space. Soil density suitable for plant growth is generally within 1.14 to 1.26 g cm^{-3}. The average soil bulk density of grassland in Qilian mountain was 1.01 g cm^{-3}, with most of the area between 0.75-1.14 g cm^{-3}. The grassland soil comprehensive fertility index of Qilian mountain decreases from east to west. The spatial distribution and succession of grassland types were the main factors affecting grassland soil fertility. From west to east, there are desert, typical grassland and meadow grassland types in Qilian mountain mainly. CV is an indicator of degree of dispersion of the sample. CV <10% means weak variation, 10-100% means medium variation and > 100% means strong variation. The results of our studies indicated that, except for soil pH, which were weak variations, the other nutrient indicators were all moderately variable.

Grassland type is influenced by climate, vegetation and soil (Hu et al., 1978). Soil as the substrate of grassland, its physical and chemical properties of different types of grasslands provide important insight to understand grassland evolution (Gou et al., 2019; Li et al., 2019). Zhang et al (2019) found that the contents of total N, organic carbon and soluble organic carbon of different alpine types of grassland were in an order of alpine meadow> alpine meadow grassland> alpine grassland> alpine desert, and the differences between alpine types of grasslands were significant. This study observed that the ranking of the different types of grassland was desert type > meadow type > steppe type for soil bulk density, the changes of total porosity were opposite to soil bulk density. Furthermore, the total N, SOM and soil comprehensive fertility index in different grassland types had significant differences. Since soil nutrients were mainly derived from the decomposition of animals, plants, microbial residues, litters, root exudates and soil parent materials, spatial heterogeneity of soil fertility distribution in different types of grassland observed in this study indicated these grasslands were influenced through the different climate and vegetation (Wei et al., 2018). Soil organic matter mainly came from the decomposition of ¿residual? organic matter, but moisture and temperature were the dominant factors controlling the decomposition rate of organic matter. This was why Ren and Hu (2008) used rainfall and temperature accumulated as a first-class classification index to classify grassland types in CSCS (Ren and Hu., 2008).

The rational construction of comprehensive evaluation factors was the key content of comprehensive evaluation of soil fertility, which directly determined the rationality and objectivity of evaluation results (Chen et al., 2019; Science - Soil Science, 2019). In many studies, the evaluation indicators of soil fertility mainly focused on nutrients such as soil organic matter, nitrogen, phosphorus and potassium (Chen et al., 2019; Science-Soil Science, 2019; Yu et al., 2018). In our study, the evaluation indexes of soil fertility incorporated the soil bulk density and total porosity, which could reflect the status of soil fertility from different angel as soil compactness, permeability, infiltration performance and water holding capacity were also reflected by soil bulk density and total porosity (Garrigues et al., 2012). The modified Nemero formula highlights the effect of the minimum factor on soil fertility, reflecting the law of the smallest factor of plant growth in ecology (An et al., 2015), and the soil minimum factor can be judged according to the minimum value of the Fi in the Nemero formula. In ours study, the different type grasslands soil fertility had different main limiting factors. Such as pH, total N and SOM were the main factors limiting soil fertility in LM, and pH and available P was the main factors limiting soil fertility in UM, AM, TS and AS. The Soil bulk density, pH, total N, SOM and available P were the main factors limiting soil fertility in TD and TDS. Soil bulk density and available P were the main factors limiting soil fertility in AD. The Nemero index method can objectively reflect the comprehensive fertility characteristics of grassland soil, but many studies have not analyzed the spatial distribution characteristics of soil fertility in depth (Bao et al., 2012; Fan, et al., 2012). Ours research combined GIS and soil science to draw a spatial distribution map of grassland soil fertility in Qilian mountain, which more intuitively reflected the distribution of grassland soil fertility. In ours study, the areas with high, medium and low soil fertility accounted for the total grassland area of Qilian mountain was 63.19%, 34.24% and 2.57%.

Grassland was an important foundation for the construction of the Qilian mountain ecosystem. Based on the research results, the actual distribution of grassland types, and reasonable management could promoted benign and sustainable development of grassland ecosystems

4 Conclusions

The results of soil fertility indexes and their spatial distribution of grasslands in Qilian mountain showed that, except for the low-available P content, other soil fertility indexes had reached level 2 and above in China's second soil census standard, while soil bulk density was relatively low and pH was relatively high. The soil comprehensive fertility index was in a ranking order of TS > AM > AS > UM > AD >LM > TDS > TD, and the areas with high, medium and low soil fertility accounted for 63.19%, 34.24% and 2.57% of the total grassland area. The main limiting factors found in the different types of grasslands and spatial distribution, the typical grasslands and meadows may need to apply acidic phosphate fertilizers, and desert grasslands to apply compound fertilizers of nitrogen and phosphorus to improve comprehensive soil fertility to improve grassland productivity

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