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Soil quality assessment under different land uses in an alpine grassland

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ABSTRACT

Soil quality index (SQI) is widely practiced form plot to national scales to assess the status and use potential of soils. However, how to objectively choose relevant indicators and score these indicators to generate comprehensive SQI is still a major challenge because of the complexity and site-specificity of soils. The objective of this study is to develop SQI using different indicators selecting methods (total data set, minimum data set and revised minimum data set) and scoring methods (linear and non-linear) to evaluate the influences of three land uses (CL, cropland; GR, grazing grassland; FE, grassland enclosure) on soil quality in an alpine grassland. Fourteen soil indicators representing soil physical, chemical and biological properties were measured at 0–20 cm depth. One-way analysis of variance and principal component analysis were used with the fourteen indicators to select the total data set, minimum data set and revised minimum data set. Eleven soil indicators exhibited treatment differences were identified as the total data set. However, only two (AN and MBC) and four (MWD, SOC, AN and MBC) soil indicators were retained in the minimum data set and revised minimum data set, respectively. The six SQIs developed in this study quantified the effects of different land uses on soil quality equally well regarding both sensitivity and accuracy. However, the differentiating ability of SQI calculated using the non-linear scoring-revised minimum data set method (SQI-NLRM) was better than other SQIs based on minimum data set and revised minimum data set because of the highest F value and greatest correlation coefficient with SQI based on total data set. Under GR and CL treatment, SQI-NLRM values were 15.15% and 69.70% lower than that under FE treatment. These results indicated that land use conversions can significantly change the soil quality in the alpine grassland, and the SQI-NLRM developed in this study provides a sensitive and effective approach for quantitative evaluation of soil quality.

1. Introduction

Soils, the non-renewable resources on human time scales, are the essence of all terrestrial life and a cultural heritage (Lal, 2015). Therefore, the conditions and sustainability of soils are closely relate to the health of human, society and environment. Soil quality is a useful concept to assess the status and changes of soils, and is defined as the soil capability to sustain plant and animal productivity, to maintain or enhance water and air quality, and to support human health and habitation (Doran and Parkin, 1994; Karlen et al., 1997).

The influences of soil management practices on soil quality are widely studied from plot to national scales worldwide (e.g. Qi et al., 2009; Askari and Holden, 2014; Bunemann et al., 2018; Liu et al., 2018; Valle and Carrasco, 2018). However, soil quality assessments are still a developing and promising field of soil science (Qi et al., 2009). Although many conceptual frameworks and models have been proposed to evaluate soil quality, there is no universal method or tool to assess soil quality under any environmental conditions (Askari and Holden, 2014; Obade and Lal, 2016; Sione et al., 2017). As an effective tool for assessing soil quality, soil quality index (SQI) is quantitatively flexible, easy to use and is closely related to soil management practices. Therefore, SQI has been successfully used to assess soil quality at many scales and locations (e.g. Andrews et al., 2002; Qi et al., 2009; Askari and Holden, 2014; Obade and Lal, 2016; Liu et al., 2018).

A practical, effective and comprehensive soil quality evaluation must be inferred by measuring soil physical, chemical and biological indicators (Sione et al., 2017). However, how to select the minimum data set indicators that incorporates both qualitative and quantitative information remains a challenge in the process of developing SQI (Obade and Lal, 2016; Guo et al., 2017). Principal component analysis

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with simple or multiple correlation analysis is an appropriate method to select indicators from diverse indicators that infers soil process and services (Swanepoel et al., 2014; Zuber et al., 2017). However, sometimes only four to six indicators are finally selected by this approach, and some important indicators that are relevant to soil physical, chemical and biological properties are usually not be included in the minimum data set (Romaniuk et al., 2011). In a study by Liu et al. (2014) in eastern China, only chemical and biological indicators were retained in their minimum data set using the principal component analysis. Similar, Andrews and Carroll (2001) found that only chemical indicators were selected by principal component analysis in the minimum data set. The lack of indicators representing soil physical, chemical and biological properties will reduce the SQI sensitivity to the changes in soil quality, and thus lead to the inaccurate results (Zuber et al., 2017). Therefore, method that selecting the restricted and interpretable set of soil quality indicators still requires further investigation (Swanepoel et al., 2014; Obade and Lal, 2016).

Once the soil indicators in the minimum data set are identified, the interpretation of the values of the proposed soil quality indicators needs to be well-defined. The linear and non-linear scoring method are the commonly used method today (Andrews et al., 2002; Masto et al., 2008; Raiesi, 2017). The shape of such curves is established based on a combination of literature values and expert judgment (Andrews et al., 2004). However, comparisons between the two scoring methods showed contradictory results due to the greatest complexity and site-specificity of soil systems and legacy effects of previous land use. Raiesi (2017) in Western Iran reported that the linear scoring method was superior to non-linear scoring method to transform and normalize the minimum data set indicators; however, Yu et al. (2018b) in the northeastern China found that the non-linear scoring method presented soil function better than linear scoring method due to its high differentiating ability to soil management practices. An indicator is only useful if its value can be unequivocally interpreted when it is used to assess soil quality (Bunemann et al., 2018). Therefore, suitable indicators scoring method should be identified before implementing SQIs to assess soil quality in a specific soil region.

Various studies have shown that indiscriminate land uses or managements are mainly responsible for a decline of soil quality due to continuing reductions of soil organic matter, nutrients and soil physical structure (Yu et al., 2014; Hall et al., 2017; Abdalla et al., 2018); however, efficient land uses can not only maintain soil quality and health, but also improve soil quality (Lal, 2015; Raiesi, 2017). Bayinbuluke alpine grassland is one of the largest grasslands in China. Due to the double influences of human activity and climate change, Bayinbuluke alpine grassland has suffered from substantial land degradation in recent decades. Grazing exclusion by fencing has been widely adopted to restore degraded grasslands and improve the soil quality in the Bayinbuluke alpine grassland. However, grazing exclusion result in the shortage of forage grass. To meet the increasing demands for forage grass, part of grasslands were cleared as a cropland to grow forage grass. The coexistence of agriculture and animal husbandry in this area leads to the diversification of land uses (Guan, 2015). The responses of soil quality to different land uses is important in addressing the issues of sustainability of agriculture and animal husbandry. However, the influences of different land uses on soil quality in the Bayinbuluke alpine grassland is largely unknown.

We hypothesized that SQI developed by the revised minimum data set in this study has better differentiating ability than other SQIs calculated by minimum data set, and the moderate grazing will not result in the grassland degradation. To address this hypothesis, the objectives of this study were to (1) develop SQIs using the sensitive indicators selecting methods (total data set, minimum data set and revised minimum data set) and standard scoring methods (linear and non-linear) for different land uses in alpine grassland; (2) compare the differentiating ability of SQIs to different land uses; and (3) investigate the influences of land use treatments on soil quality in alpine grassland.

2. Materials and methods

2.1. Study area

The study was conducted at the Bayinbuluk Grassland Ecosystem Research Station, Chinese Academy of Science (42°53.1′ N, 83°42.5′ E, 2500 m a.s.l.). Bayinbuluke alpine grassland is located in the southern Tianshan Mountains, Central Asia, and covers a total area of approximately $2.3 \times 10^4\ km^2$. The annual average air temperature and precipitation are −4.6 °C and 273.5 mm, respectively, from 1956 to 2015, and approximately 70%–80% of the total precipitation occurs between June and September. The coldest monthly average air temperature is −27.4 °C in January and the warmest is 11.2 °C in July. The soil of the study area is a silty clay loam, which are classified as Mat-Cryic Cambisols in Chinese Soil Taxonomic System or as borolls in the USDA soil taxonomy. The dominant native species belong to the Gramineae and include *Stipa purpurea*, *Festuca ovina*, and *Agropyron cristatum* (Li et al., 2012).

2.2. Experimental design and soil sampling

Three land use treatments were established in this study. Land use treatments were moderate grazing grassland (GR) grazed by 2 sheep per hectare in winter (100 ha), fencing grassland (FE) ungrazed since 1984 (0.25 ha) and cropland site (CL) that converted from grassland to cropland since 2014 (55 ha). GR and FE sites are dominated by *Stipa purpurea* and *Festuca kryloviana*, and are a dry grassland type. The vegetation coverage measures 60% and 90% for GR and FE treatments, respectively. The above-ground biomass was $318\ g\ m^{-2}$ and $515\ g\ m^{-2}$, and the below-ground biomass in the 0–20 cm depth was $1.70\ kg\ m^{-2}$ and $2.30\ kg\ m^{-2}$ for GR and FE treatments, respectively. The cropland treatment followed the tradition cropland practice in the Bayinbuluke grassland, which consists of growing *Avena sativa*, plowing the soil once before the crop growing season down to 20 cm and approximately 1.05×10^5 kg–1.20×10^5 kg sheep manure per ha was applied once every three years at sowing. No chemical fertilizers were used and approximately 4000 to $6000\ m^3\ ha^{-1}$ of water was applied using the drip irrigation technology in the study site.

Six sample plots (each 0.5 m × 0.5 m) were established at 10 m intervals along a random transect in each land use treatment. Soil samples at 0–20 cm depth were collected in middle April 2017 with a 5-cm-diameter soil core sampler after removing the above ground biomass and litter. A sample was composed by mixing sub-samples from two adjacent selected locations. The soil samples were gently mixed, and the visible roots, plant residues and stones were removed. One subsample was stored field-moist in a cooler at 4 °C for biological analysis. Another sub-sample was air-dried, and then prepared to be analyzed for physical and chemical properties.

2.3. Soil analyses

Physical, chemical and biological properties were determined to develop soil quality indices and assess the effects of land uses according to their appropriateness to the task (including the ease, sensitiveness and reliability of measurement) and the relevance, representation of key properties controlling soil quality in the study area based on our study experiences. Fourteen soil indicators were measured per sample using the corresponding standard laboratory analytical methods. Bulk density (BD) was determined by the core method (Yu et al., 2014). Soils were physically fractionated using a modified wet sieving fractionation scheme and the geometric mean diameter (GMD) and mean weight diameter (MWD) were calculated used the method of Nath and Lal (2017). Soil temperature (ST) was measured by a temperature probe (Davidson et al., 1998). Soil water content (SW) was measured with the oven-drying method (105 °C, 12 h) (Lu, 2000). Soil organic carbon (SOC) was measured using the modified Walkley-Black method (Yu

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