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Selecting the minimum data set and quantitative soil quality indexing of alkaline soils under different land uses in northeastern China

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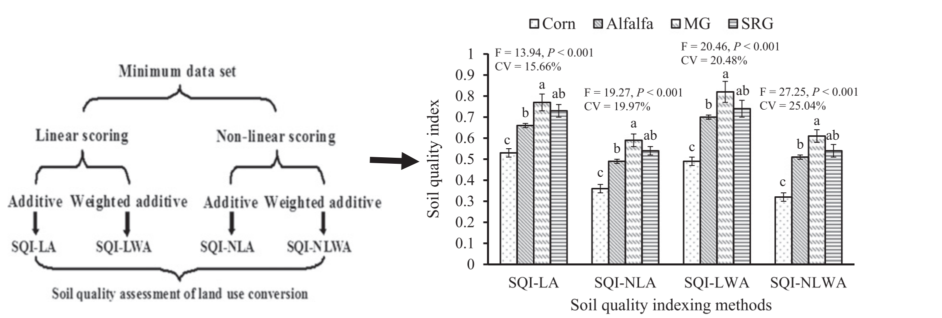
HIGHLIGHTS

- Invertase, N:P ratio, water-extractable organic C and labile C were identified as the MDS.
- SQI was an effective tool to assess the impacts of agricultural management practices on SQ.
- SQI-NLWA showed the best discrimination by different land-use treatments.
- Conversion of cropland to forage or grassland significantly improves SQ in NE China.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding the influences of land use conversions on soil quality (SQ) and function are essential to adopt proper agricultural management practices for a specific region. The primary objective of this study was to develop soil quality indices (SQIs) to assess the short-term influences of different land uses on SQ in semiarid alkaline grassland in northeastern China. Land use treatments were corn cropland (Corn), alfalfa perennial forage (Alfalfa), monoculture *Lyemus chinensis* grassland (MG) and successional regrowth grassland (SRG), which were applied for five years. Twenty-two soil indicators were determined at 0–20 cm depth as the potential SQ indicators. Of these, thirteen indicators exhibited treatment differences and were identified as the total data set (TDS) for subsequent analysis. Principal component analysis was used with the TDS to select the minimum data set (MDS), and four SQIs were calculated using linear/non-linear scoring functions and additive/weighted additive methods. Invertase, N:P ratio, water-extractable organic carbon and labile carbon were identified as the MDS. The four SQIs performed well, with significant positive correlations ($P < 0.001$, $n = 16$) among them. However, the SQI calculated using the non-linear weighted additive integration (SQI-NLWA) had the best discrimination under different land-use treatments due to the higher F values and larger coefficient of variance as compared to the other SQIs. The SQI value under the MG treatment was the highest, followed by that under the SRG and Alfalfa treatments, and all of these were significantly higher than that of Corn treatment. These results indicated that conversion of cropland to perennial forage or grassland can significantly improve the SQ in the Songnen grassland. In addition, SQI-NLWA can provide a better practical, quantitative tool for assessing SQ and is recommended for soil quality evaluation under different land uses in semiarid agroecosystems.

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1. Introduction

Soil is vital to humans because it not only influences the quantity and quality of food and fiber production but also supports ecosystem biodiversity and functions (Nakajima et al., 2015). Given that crops support most of the human population, sustainable use of soil resources is essential for long-term human health (Wall et al., 2015). Maintaining maximum long-term productivity without decreasing soil quality (SQ) and resulting soil degradation is the premise for the sustainable use of soils (Qi et al., 2009; Askari and Holden, 2014). Therefore, quantification of SQ under different soil management practices is important to distinguish problem areas, provide early warning signs of adverse trends, and evaluate sustainable soil use management (Doran and Zeiss, 2000; Nakajima et al., 2015). A reliable and accurate SQ evaluation is the key in better understanding SQ under different soil management practices (Guo et al., 2017; Obade and Lal, 2017). Soil quality entails the capacity of a specific type of soil to function within natural or managed boundaries, to sustain plant and animal survival and maintain environmental quality (Andrews et al., 2004; Raiesi, 2017). No single measure can directly determine SQ, but SQ can be assessed by measuring the soil physical, chemical and biological properties (Obade and Lal, 2017). Although different conceptual frameworks and models have been developed for SQ evaluation, from qualitative approaches to quantitative methods (e.g., Andrews et al., 2004; Karlen et al., 1997; Paz-Kagan et al., 2014; Askari and Holden, 2014; Obade and Lal, 2017), these are either too labor intensive or too site specific, and a universal model or method to assess soil quality remains elusive due to the great complexity and variability of soil systems (Obade and Lal, 2017). Thus, the reliable and accurate evaluation of SQ at a regional, national or global scale requires further investigation (Guo et al., 2017; Obade and Lal, 2017).

Soil quality evaluation is still a developing and promising field of soil and agriculture science (Qi et al., 2009). Reliable and accurate evaluation results of SQ depend on appropriate analysis methods. Soil quality index (SQI), the most commonly used method today, synthesizes measured soil indicators into a simplified format based on an integrated evaluation of SQ indicators and their weights that can support multi-objective decision making (Askari and Holden, 2014; Obade and Lal, 2016). SQI has been successfully used at many scales and in many regions for SQ assessment under different agricultural management practices (e.g., Andrews et al., 2002; Qi et al., 2009; Gong et al., 2015; Raiesi, 2017; Zhao et al., 2017). However, how to objectively combine quantitative and qualitative soil indicators to generate comprehensive SQIs is still the major challenge in SQ determination (Obade and Lal, 2016). There is a range of indicator selections, indicator scoring and numerous scores integration methods, each developed for specific purposes, using for holistic SQI calculating; however, these SQIs are usually valid under particular environmental conditions, and limited research has focused on method comparisons and selection before implementing these methods in a specific soil region (Qi et al., 2009; Askari and Holden, 2014; Guo et al., 2017).

Songnen grassland, the main component of the northern agro-pastoral zone of China, has suffered substantial land salinization and alkalinization due to a conversion of 26.4% of grassland to cropland from 1986 to 2000 in order to meet the urgent need for higher crop production to feed a rapidly growing population (Liu et al., 2009). However, there is now an oversupply of corn production in China, resulting in a substantial decline of corn prices (Chen et al., 2016). In response to the land degradation and the decline of farmers' income, the Chinese government has carried out a series of policies and subsidies to guide farmers to convert cropland to forage or grass planting land in the regions in which the soils are not suitable for growing crops to improve the development of animal husbandry (Ministry of Agriculture of the People's Republic of China, 2015). A change in land use, including urbanization, agriculture, deforestation and desertification, is the primary factor that influences SQ and sustainability of soil productivity (Askari and Holden, 2015; Gong et al., 2015; Raiesi, 2017). However, the effect of the conversion from cropland to forage or grassland on SQ has yet to be quantified in northeastern China.

We hypothesized that SQI was an effective tool for assessing the impacts of different land uses and management practices on SQ. Thus, the main objectives of this research were to (1) identify the minimum data set (MDS) consisting of key soil indicators for SQ assessment, (2) develop an SQI using the most appropriate scoring function (linear or non-linear) and integrating procedure (additive or weighting additive) for different land uses in the Songnen grassland, and (3) investigate the effects of different land uses on SQ.

2. Materials and methods

2.1. Study area

The study was conducted at the Changling Ecological Research Station for Grassland Farming (44°33′ N, 123°31′ E, 145 m a.s.l). The station is in the southern Songnen Grassland. The area is characterized by a temperate, semiarid continental monsoon climate with an annual average air temperature and precipitation of 5.9 °C and 427 mm, respectively, from 1980 to 2013, and approximately 70%–80% of the total precipitation occurs between June and September. Pan evaporation is approximately 1600 mm. The frost-free period is approximately 140 days. The soils of the study area are alkali-saline with a soil texture of 23% sand, 35% silt and 42% clay, and which are classified as Solonetz in the World Reference Base for Soil Resources (IUSS Working Group, 2015). The soils have a high content of free sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3), and the pH of the soils is between 8.0 and 11.0. The dominant native species include *Leymus chinensis, Chloris virgata, Puccinellia* spp. *and Polygonum gracilius*. The native vegetation coverage measures 50%–90%, with 100–360 g m^{-2} of aboveground biomass during the peak season (Yu et al., 2014).

2.2. Experimental design and soil sampling

The experiment was established in early May 2011 at a cropland site and ran for five years until soil sampling (Yu et al., 2017). Because of the continuous plowing and uniform management, soil conditions in the cropland before this experiment were nearly the same. Four land use treatments were established in a block design with four replications. The four treatments were corn cropland (Corn), alfalfa perennial forage (Alfalfa), monoculture *Lyemus chinensis* grassland (MG), and successional regrowth grassland (SRG). The block size was approximately 60 m × 50 m whereas the plot size was 12 m × 50 m for the Corn and Alfalfa treatments and 6 m × 50 m for the MG and SRG treatments. There was a 2-m buffer between the blocks and a 1-m buffer between the plots. The cropland was under continuous corn monoculture since 2011. The Corn plots followed the tradition cropland practice in the Songnen grassland, which consists of plowing the soil at least twice before the crop growing season down to 20 cm and fertilization (74 kg N ha^{-1}, 22 kg Pha^{-1}, and 41 kg K ha^{-1}) twice per year, at sowing and in mid-July. The Alfalfa plots were set up in May 2014. Before 2014, these plots were croplands without tillage (no tillage) while the other practices were the same as those of the previously described conventional cropland. However, the growth of corn was very poor in this no-tillage cropland in 2011 to 2013 due to the poor soil conditions and short-term land use. Considering the poor natural conditions and the development of local animal husbandry, we changed the no-tillage cropland to alfalfa forage land in May 2014 with a sowing density of approximately 1200 seeds m^{-2}. Seeds of *Lyemus chinensis* were sowed in May 2011 with a density of approximately 2000 seeds m^{-2} in the treatment plots of monoculture grasslands. Reseeding had a positive effect on the recovery of vegetation and the aboveground biomass reached approximately 100–120 g m^{-2} in early September 2011. The cropland was abandoned in 2011 in the SRG plots to restore grassland without any disturbance. The dominant species in the SRG plots included *Chloris*