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A minimum data set and soil quality index to quantify the effect of land use conversion on soil quality and degradation in native rangelands of upland arid and semiarid regions

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ABSTRACT

Conversion of native rangelands to croplands potentially influences soil functions and quality. The aim of the current study was to assess soil quality (SQ) after rangeland conversion and degradation for more than 40 years using an indexing framework and integrated approach. Fifteen soil attributes were measured at two sampling depths (0–20 and 20–40 cm) of paired native undisturbed and adjacent cultivated rangelands at three rangeland sites. The soil organic carbon (OC), electrical conductivity (EC) and arylsulphatase (ARY) activity were found to be the key indicators of the minimum data set and these indicators greatly affected the computed soil quality index (SQI), particularly in the soil surface. The contribution of OC, EC and ARY to the overall SQI was 77, 13 and 10%, respectively. Although rangeland conversion reduced other soil attributes (including aggregate stability, available water capacity, cation exchange capacity, microbial biomass, microbial activity and the activities of urease and invertase enzymes), in particular at the 0–20 cm depth, these variables did not contribute to the estimated SQI values because of their high correlation with OC contents (i.e., strong interdependency). Cultivated rangelands were characterized by a low soil OC content, EC and ARY activity, and consequently a low SQI. A significant decline in SQI value (29–47%) was observed as a result of rangeland conversion to croplands, depending on soil depth considered and scoring function used to compute the SQI. Overall, converting native rangelands to croplands decreased SQ to 52–64% of their potential capacity using a non-linear scoring method. In summary, soil OC, EC and ARY are the most important indicators, which can be used to monitor and asses the degradation of rangeland SQ after conversion to croplands in these arid and semiarid upland environments. This finding is of especial importance because the assessment of SQ allows the successful and straightforward discrimination between rangeland and cropland ecosystems or to quantify land use conversion effects on SQ. It is concluded that the rate of soil changes can be assessed and compared more accurately in the studies of land use conversions in native rangeland ecosystems using the current indexing framework due to its simplicity and quantitative flexibility.

1. Introduction

Rangeland ecosystems, covering about 40% of the world's land surface area (White et al., 2000; Suttie et al., 2005), are an essential component of biogeochemical cycles and provide key ecosystem goods and services (Lal, 2002; Suttie et al., 2005). They are of great importance not only in food and fiber production for the future world population but also for supporting biodiversity and sustaining fodder for the world's livestock; and controlling flood and soil erosion (White et al., 2000). Nevertheless, the capacity of native rangelands to provide different ecosystem services depends largely upon their management and future use for agriculture, the degree of soil change and degradation (White et al., 2000; Dormaar and Willms, 2000; Franzluebbers et al., 2000; Saviozzi et al., 2001; Whalen et al., 2003; He et al., 2008). More specifically, rangeland health and how they are functioning is reliant on their soil quality (SQ) and functions in the long-term (Herrick et al., 2002; Li et al., 2013).

Soil quality was originally defined as the capacity of soil to function within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant growth as well as animal health (Doran and Parkin, 1994; Karlen et al., 2001). The SQ takes into consideration several soil physical, chemical and biological properties either individually or jointly

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(Karlen et al., 2001; Andrews et al., 2004) to determine if soil functioning under different land uses and management practices is aggrading, sustaining, or degrading (Karlen et al., 2003). Often, a combination of more measures of soil attributes is used as SQ indicators (Andrews et al., 2004; Karlen et al., 2006; Masto et al., 2008). On the other hand, dynamic soil properties such as soil organic matter (SOM), aggregation and most microbial attributes are more responsive to management practices, disturbance and/or land use changes (Carter, 2002; Bastida et al., 2006; Masto et al., 2008; Li et al., 2013). Microbial and biochemical attributes per se can systematically represent potential indicators of SQ for its assessment following ecosystem disturbance and stress because of their high sensitivity (Gil-Sotres et al., 2005; Bastida et al., 2006; Lopes et al., 2013). However, SQ and its assessment are soil- and site-specific and will vary according to site-specific controlling factors, such as climate (temperature and precipitation), intended land use or inherent soil properties (Karlen et al., 2006).

Land use conversions can often lead to negative changes in soil functions (Saviozzi et al., 2001; Emadi et al., 2009; Spohn and Giani, 2011; Raiesi and Beheshti, 2014); therefore, comprehensive tools and methods are necessary to assess these changes using the perception of SQ. Besides, for a consistent and accurate assessment of SQ a systematic method is required for interpreting and measuring soil properties (Granatstein and Bezdicek, 1992), and individual soil attributes may not be adequate indicators of SQ (Masto et al., 2007; Mukherjee and Lal, 2014). The individual indicators are often interdependent and may respond to land use changes in a different way, confounding their effects (Karlen et al., 1997). Previous studies have focused on individual soil properties in the studies of land use conversions in rangeland ecosystems (Emadi et al., 2009; Spohn and Giani, 2011; Salek-Gilani et al., 2013; Raiesi and Beheshti, 2014), and much less attention has been paid to comprehensive assessment of SQ changes using an integrated approach. Although SQ assessment was used as a tool to quantify and evaluate the effects of soil management practices and tillage systems (Hussain et al., 1999; Shukla et al., 2006; Armenise et al., 2013), land use type (Masto et al., 2008; Rahmanipour et al., 2014) and cover crop (Fu et al., 2004; Bastida et al., 2006; Navas et al., 2011) on soil function, this technique has been used less frequently to study and determine the effects of land use changes and cultivation on SQ of native ecosystems and grassland degradation (Lopes et al., 2013; Li et al., 2013). Soil quality index (SQI) was an effective tool for assessing the SQ of alpine grasslands and quantifying the negative effect of human disturbance on SQ and grassland degradation (Li et al., 2013). However, specifically the systematic assessment of SQ for rangeland ecosystems converted into croplands is far less common and has not been reported.

Native rangeland ecosystems in Iran, covering around 56% of the total land area, are faced with critical soil degradation and subsequent low productivity due to continuing reductions of SOM, soil structure and nutrients (Emadi et al., 2009; Ayoubi et al., 2014; Raiesi and Beheshti, 2014). Conversion of rangelands to croplands (Emadi et al., 2009; Ayoubi et al., 2014), and overgrazing pressures (Mofidi et al., 2012; Raiesi and Riahi, 2014) at a large scale are mainly responsible for a decline of soil fertility and quality of arid and semi-arid rangelands throughout the country. Much soil degradation is assumed to take place in upland rangelands, particularly because of large-scale conversion of native rangelands into cultivated rangelands over the last decades. However, the impact of rangeland conversion on SQ in arid and semiarid areas of Iran is largely unknown. An understanding of rangeland SQ and its assessment is necessary for an accurate prediction of future land use and management systems (Herrick et al., 2002). Such cultivation-induced changes in SQ are yet to be characterized for native rangelands located in upland arid and semi-arid ecosystems. Thus, the main objectives of this research were to (i) determine a MDS and identify key indicators of SQ, (ii) develop a SQI using scoring function curve, and (iii) use the overall SQI for discriminating the processes and effects of land use conversions and environmental management. Fifteen soil properties were measured as potential SQ indicators for computing the SQI in this study. It was hypothesized that SQ assessment would be an effective tool to discriminate the undisturbed and disturbed (degraded) rangeland ecosystems. Additionally, sensitivity index and stratification ratio were also used to identify the most responsive soil attributes following conversion of rangelands to croplands.

2. Materials and methods

2.1. Description of experimental sites

The study sites were located at Kangavar (site1) in Kermanshah province, at Dehnow (site2) in Chaharmahal va Bakhtiari province and at Soltaniah (site3) in Zanjan province, western Iran (Fig. 1). The soils at the study sites were derived from calcareous fluvial parent sediments, and were classified as Typic Haploxerepts (Kangavar and Dehnow) and Typic Calcixerepts (Soltaniah) according to Key to Soil Taxonomy (Soil Survey Staff, 2010). We considered consistency in soil texture and parent material, slope aspect and position, and land use type and history when selecting the sites. We grouped each study site into two land use types, namely native rangelands and croplands, indicative of current land utilization. The differences in soil attributes between native rangelands and adjacent croplands at each study site can be only due to the land use history and vegetation changes since both land uses have the same suite of soil-forming factors and are therefore geo-referenced points. Soil samples from the uncultivated rangelands served as a control and were used for comparison with those from the cultivated rangelands to determine whether land use changes were causing deterioration of the SQ. The selected native rangeland ecosystems are moderately degraded due to long-term sheep grazing and have low cover crop with shrubs as predominant species. Table 1 presents a brief description and site history of the study rangelands. The three study sites are characterized by a seasonal fluctuation of water table level (Table 1).

2.2. Soil sampling, preparation and analyses

The paired sampling points were native rangeland and adjacent cropland plots with similar slope aspect and parent materials at each study site. At each paired point, three plots (about 3.0 ha) of each land use were selected for soil sampling in rangelands and their corresponding croplands at each study site. The composite soil samples were collected from the 0 to 20 and 20 to 40 cm layers at late spring and early winter, before tillage operation and fertilizer application in cultivated plots. From each plot, 15 individual soil samples were collected using a soil auger, mixed together thoroughly and pooled in the field to make a composite sample representative of each land use. Visible roots, organic residues and rock fragments were removed manually at sampling time. Soil samples (3 kg) were air-dried, crushed and passed through a 2-mm sieve for physical and chemical analysis. Field moist soil samples (2 mm, 1 kg) were also obtained and stored at 4 °C for the analysis of microbial properties. The following attributes were measured: soil available water capacity (AW), aggregate mean weight diameter (MWD), electrical conductivity (EC), cation exchange capacity (CEC), organic C (OC), total nitrogen (TN), microbial biomass C (MBC) and N (MBN), C (Cmin) and N (Nmin) mineralization, and the activity of urease (URE), alkaline phosphatase (ALP), acid phosphatase (ACP), invertase (INV) and arylsulphatase (ARY). Table 2