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A comparison of soil quality evaluation methods for Fluvisol along the lower Yellow River

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ABSTRACT

Soil quality evaluation as a decision-making tool to improve understanding of soil quality is essential for grading croplands and adopting proper agricultural practices. Various methods of soil quality evaluation have been developed, which have occasionally generated inconsistent evaluation results between differing soil types. The applicability of these techniques is seldom tested before implementing an evaluation method on a specific soil region. Fluvisol is an important soil resource for agriculture in China, especially for irrigation districts along the lower Yellow River. In the present study, the soil quality of two typical agricultural counties (Yucheng and Kenli) along the lower Yellow River was evaluated using four commonly utilized methods. In the two counties, the overall spatial patterns of soil quality derived from the four methods were similar, with differences in details existing among these methods. The soil quality in Yucheng, ranging from moderate to high, is superior to that observed in Kenli, where salinity is the primary limiting factor. In addition, the applicability of soil quality evaluation methods on the Fluvisol was investigated. It was found that the integrated quality indexing-linear scoring (IQI–LS) and the Nemoro indexing-linear scoring (NQI–LS) methods were the most accurate and practical of the four methods studied. These methods, which are based on the total data set of indicators, show better performance for soil quality evaluation on a Fluvisol. Further, different evaluation methods based on the minimum data set of indicators were compared, considering both the accuracy of the evaluation and the economic cost of obtaining the soil data. The results from the present study indicate that the IQI–LS method based on the minimum data set of indictors is recommended for large-scale soil quality evaluations.

1. Introduction

Soil quality can be defined as "the capacity of soil to function to sustain plant and animal productivities, to maintain or enhance water and air quality and to support human health and habitation" (Doran and Parkin, 1994; Karlen et al., 1997). An understanding of soil quality is important to identify problem areas, assess sustainable agricultural management, and provide early warning signs of adverse trends (Doran and Zeiss, 2000; Marzaioli et al., 2010; Takoutsing et al., 2016). Improved understanding of soil quality comes from a reliable and accurate soil quality evaluation, which is a decision-making tool that effectively combines a variety of soil information to analyze quantitatively the quality of the soil. Soil quality indexing is the most commonly used method, because it is easy to implement and is quantitatively flexible (Andrews et al., 2002; Swanepoel et al., 2014). Soil quality indexing normally includes three steps: (1) choosing appropriate indicators, (2) scoring the indicators, and (3) combining the indicator scores into an index.

Physical, chemical, and biological properties of the soil that can influence soil production and are sensitive to environmental changes are typically chosen as soil quality indicators (Nosrati, 2013; Takoutsing et al., 2016). Biological indicators and microbial indicators, in particular, have recently attracted more attention, owing to their use in evaluating the short-term effects of environmental changes on soil function (Dose et al., 2015; Niemeyer et al., 2012). However, microbial indicators are seldom used in regional studies because measuring the soil microbial properties of large sample sizes is costly. Several previous studies have reported a correlation between the biological and physicochemical properties of soil, such as between dehydrogenase activity and chemical indicators (e.g., soil organic matter, pH, and nutrients) (Cardoso et al., 2013; Doi and Ranamukhaarachchi, 2009). Therefore, some of the biological properties of soil might be partly explained by physicochemical properties. The selection of indicators should consider all available information regarding the experimental area and is therefore largely

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dependent on expert opinion and reviews of previous studies (Andrews et al., 2004; Pardo et al., 2014). However, experimental analyses are extremely difficult to implement in a large-scale area, owing to the large amount of soil quality indicators required. Consequently, new methods need to be developed to reduce the number of indicators necessary for these evaluations, with the aims of enhancing work efficiency and reducing labor time and expense. Andrews et al. (2002) and Imaz et al. (2010) obtained a minimum data set of indicators from a total data set using factor analysis, and reported a high consistency in soil quality evaluation between the two date sets.

During the scoring of indicators, data normalization is required, because indicators are usually expressed with different numerical scales. Of the available techniques for data normalization, the rating chart method is relatively simple—it first rates indicators based on measured values and then allocates scores to each rating (Amirinejad et al., 2011). In addition, Swanepoel et al. (2014) and Liu et al. (2014) used the linear scoring (LS) method to normalize data. This method establishes the linear relationship between the quality score and measured data based on the sensitivity of the indicator to changes in the soil quality. Moreover, other studies found no linear relationship between quality scores and indicator values, and thus developed the no-linear scoring (NLS) method to normalize data (Bi et al., 2013; Cambardella et al., 2004). The NLS method differs from the LS method, which depends on measured values of indicators, by requiring improved knowledge regarding soil and crop systems in the study area.

After indicator scoring, the scores of selected indicators are combined into a soil quality index through several systematic approaches, such as averaging (Svoray et al., 2015), summing (Cambardella et al., 2004), and multiplying (Amirinejad et al., 2011). The above three calculation methods are convenient to use, but they do not account for differences in the contribution of each indicator to soil quality. The integrated quality indexing (IQI) method, which takes the significance of each indicator into account, specifies the weight value of each indicator during the indexing of scores (Bi et al., 2013; Congreves et al., 2015), with the weight value allocations based on expert opinion or statistical analysis (Glover et al., 2000; Liu et al., 2014). Several studies have also highlighted the influence of the limiting factor of the soil quality, and employed a Nemoro quality indexing (NQI) method, which evaluates the soil quality based on the minimum and average indicator scores (Rahmanipour et al., 2014; Wang et al., 2014).

Accurate evaluation results depend on appropriate analysis methods; however, recommendation of a specific soil quality evaluation method must be carefully considered and will vary by site, given that soil systems have great complexity and variability (Congreves et al., 2015; Nosrati, 2013). Therefore, choosing a suitable method to evaluate the soil quality for a specific soil or region is essential. There are a range of possible methods, each with advantages and disadvantages, which have been developed to evaluate soil quality; however, limited studies have focused on method comparisons and selection. Consequently, applicability of evaluation methods on a specific soil or region is not fully understood. Irrigation districts along the lower Yellow River are the primary growing regions in China with Fluvisol (in UNFAO) being the main agricultural soil type. It is challenging to choose a suitable method to evaluate precisely the soil quality on the Fluvisol along the lower Yellow River.

The present study evaluated the soil quality of two typical agricultural counties (Yucheng and Kenli) along the lower Yellow River using four methods of the integrated quality indexing–linear scoring, the Nemoro quality indexing–linear scoring, the integrated quality indexing–no-linear scoring, and the Nemoro quality indexing–no-linear scoring, whereby performances of different soil quality evaluation methods on a Fluvisol were compared based on their accuracy and practicability. In addition, the applicability of methods based on the minimum data set was investigated for future, large-scale evaluation studies. Through methods comparison, the appropriate method could facilitate to map soil quality and make management strategies.

2. Material and methods

2.1. Site description and soil sampling

The present study was conducted in two typical agricultural counties along the lower Yellow River: Yucheng County (116°22′–116°45′ E, 36°40′–37°12′ N, 19.2–27.3 m a.s.l.) and Kenli County (118°24′–119°10′ E, 37°21′–38°9′ N, 2.0–11.6 m a.s.l.) (Fig. 1). Yucheng County has a warm, temperate, semi-humid monsoonal climate, with an average annual air temperature of 13.1 °C and an average rainfall of 616 mm. Approximately 70% of the annual precipitation occurs between June and September, and January and July are the coldest and warmest months of a year, with average monthly air temperatures of −0.4 and 25.9 °C, respectively. In addition, Yucheng County is located on the fluvial plain of the Yellow River, where the land is flat, the soils are classified as Calcaric Fluvisols, according to the FAO-UNESCO system (FAO, 1988), the surface soil texture is loam, and the most common cropping system is summer maize–winter wheat rotation. Kenli County has the same climate as Yucheng County, with an average annual air temperature of 11.9 °C and an average rainfall of 592.2 mm. Approximately 70% of the annual precipitation occurs in July and August, and January and July are the coldest and warmest months of the year, with average monthly air temperatures of −8.5 and 26.0 °C, respectively. In addition, Kenli County is located on the east of the fluvial plain, where the land slopes from the southwest to the northeast, the soils are characterized as Salic Fluvisols, according to the FAO-UNESCO system, the surface soil texture is loam, and the main crop is cotton. Extensive chemical fertilizer application and frequent tillage have been degrading the soil of the district's farmland since the 1980's, which is when intensive agricultural production began to flourish in China. However, soil salinization is another limiting factor for crop planting in this region, owing to the occurrence of shallow (<3 m) and highly saline (>2 g L^{-1}) underground water.

Soil samples were collected from farmlands between harvest and the next cropping season. The study areas (Yucheng County and Kenli County) were divided into 4 km × 4 km networks, and the soil samples were collected from the centers of these squares. Ultimately, a total of 70 soil samples were collected from each county (Fig. 1), and the location of sampling point was recorded using a handheld GPS. In addition, each soil sample was a composite of four subsamples (0–20 cm) that were taken from an area of ~314 m^2 (diameter of 20 m) within an agricultural field, fully mixed, and stored in plastic bags until analysis.

2.2. Laboratory analyses

Soil samples were air-dried and passed through a 2-mm sieve. Soil organic matter (SOM) was measured using the Walkley-Black method (Nelson and Sommers, 1982). Total nitrogen (Total N) was determined using the Kjeldahl digestion method (Bremner and Mulvaney, 1982). The spectrophotometer detection method was used to determine total phosphorus (Total P) after the digestion of samples (Olsen and Sommers, 1982). Available phosphorus (Available P) was determined by extracting samples with a 0.5 mol L^{-1} sodium bicarbonate solution, and detection with a spectrophotometer (Olsen et al., 1954). Total potassium (Total K) was determined using sodium hydroxide melting-flame photometry detection (Lu, 2000). Available potassium (Available K) was determined by extracting samples with a 1 mol L^{-1} ammonium acetate solution, and detection with a flame photometer (Lu, 2000). Soil pH was determined using the electrometric method on a soil/water suspension (Pansu and Gautheyrou, 2006). Electrical conductivity (EC) was determined on aqueous soil extracts with a conductivity meter (Rhoades et al., 1989). Dry bulk density (BD) was determined gravimetrically using 100-cm^3 undisturbed soil cores (Blake and Hartge, 1986). Water stable aggregation was determined using the sieve-pipette method (Gee and Bauder, 1986), and the mean weight diameter (MWD) was