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Soil quality index of a crosby silt loam in central Ohio

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ABSTRACT

Soil quality index (SQI) assessment is an important tool for evaluating land use and soil management practices in agroecosystems. Thus, the objectives of this research were to assess SQI using the scoring function analysis for different agricultural management practices, and to evaluate the effects of tillage and drainage systems on SQI of a crosby silt loam in central Ohio. Treatments included two tillage: no-till (NT), chisel tillage (CT), and two drainage factors: drainage (D) and no-drainage (ND). Three main steps were followed for the SQI assessment: (1) identification of the minimum data set of indicators, (2) indicator interpretation, and (3) integration of all indicator scores into one SQI value. The data showed that saturated hydraulic conductivity (K_{sat}) and soil organic carbon (SOC) concentration were the most discriminating and key indicator for SQI assessment. The SQI was not significantly affected by subsurface drainage treatment ($D = 0.69$ and $ND = 0.70$, $P = 0.763$). The results imply that long-term NT and subsurface drainage may not significantly alter the SQI because of the effects of weather condition, crop rotation, and weed-control. The SQI was significantly correlated with corn yield ($R = 0.62$, $P < 0.05$; $n = 12$), suggesting that the SQI is an effective and useful tool for assessing the agronomic productivity. The SQI computed by the method described is a useful tool to synthesize the soil and agronomic information.

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1. Introduction

Soil quality index (SQI) is a tool for assessing the impacts of land use and soil management practices (Karlen, 1997). Assessing soil quality is important for the biosphere functioning not only in the production of food and fiber but also in the maintenance of local, regional, and global ecosystem functions (Doran and Parkin, 1994). A committee by the soil science society of America (SSSA) in 1994, defined the concept, examined its rational and justification, and identified key soil parameters for evaluating soil quality (Karlen et al., 2003). Soil quality refers to 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). The SQI reflects soil physical, chemical, and biological properties, and processes and interactions within each soil resource and their interactions within each soil (Karlen et al., 2001). Additionally, proper/improper managements may lead to positive/negative changes in soil functions; therefore, a need for comprehensive tools and methods to assess these changes by evaluating SQI is recognized (Andrews et al., 2004; Karlen and Stott, 1994). Furthermore, SQI can be used to monitor trends in soil properties and functions over time, to determine if soil quality under different land use and management is aggrading, sustaining, or degrading soil attributes (Karlen et al., 2003). When the soil is not functioning to its capacity as a result of constraints, long-term sustainable productivity may be jeopardized. Three general approaches to assess soil quality include: (1) comparing management practices for differences in soil quality, (2) comparing the same site over time and establishing trend as a dynamic assessment, and (3) comparing the problem areas vs. non-problem areas within the site (Larson and Pierce, 1994).

However, there is no universal method or tool to assess soil quality, although investigators have proposed conceptual frameworks and models to evaluate soil quality (Andrews et al., 2004; Armenise et al., 2013; Hussain et al., 1999; Karlen and Stott, 1994; Lee et al., 2006; Shukla et al., 2006). Thus, SQI has been assessed by linear and multiple regression analysis (Mendham et al., 2002), pedotransfer functions analysis (Salchow et al., 1996), principle component analysis (PCA) (Armenise et al., 2013; Shukla et al., 2006), and scoring function analysis (Karlen et al., 2008). An SQI can be ranked from 0 to 1 through scoring function analysis, these values can be easily interpreted to reflect soil properties under specific situations. The minimum data set of soil indicators can be

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combined into one SQI through a flexible process (Lee et al., 2006). The processes involve establishing criteria and conditions to guide the evaluation, such as by establishing ranges for indicator values that are appropriate for the specific soils, and determining the relative importance or weight that should be given to each indicator (Lee et al., 2006).

Since soil quality varies with management, such as in a no-till (NT) system which may increase the soil organic carbon (SOC) pool (Six et al., 2004). Globally, 146 Mha of arable land has poorly drained soils and is in need of some drainage management to improve soil physical properties, reduce risks of soil erosion, and improve crop growth. A large area of cropland in Ohio is in need of drainage (Randall and Iragavarapu, 1995).

Thus, the objectives of this research were to (1) develop an SQI using scoring function analysis for different agriculture management practices, (2) identify key indicators of soil quality, and (3) determine relation between SQI and agronomic yield.

2. Materials and methods

2.1. Site description

Data for SQI assessment were obtained an 18 years experiment to study the impacts of drainage and tillage on soil properties. The experiment was established in 1994, at the Waterman Farm of the Ohio State University, Columbus, OH, USA (40°02′29N, 83°02′68W). Soils of the site are classified according to US Soil Taxonomy (Soil) as Crosby silt loam (fine, mixed, mesic, aeric ochraqualf). The experiment field layout consisted of two tillage treatments, (NT vs. chisel-tillage (CT)), and two drainage treatments, with three replications in a randomized block design. The NT plots have not been disturbed or plowed either before or after the establishment of the research site since 1994. The CT treatment consisted of fall chisel plowing to a depth of approximately 20 cm, and spring disking. The tile drainage was installed in the spring of 1994 and, it consists of perforated plastic tubing (Sullivan, 1997). The tubing is 10 cm in diameter and was installed at about 100 cm. On the east side of each drainage plot, a sump was constructed for the collection of sub-surface drainage water. Corn (*Zea mays* L.) has been continuously cultivated on this site since the experiments started in 1994. Each plot area is 27.4 × 27.4 m and plots are separated by 6.1 m grassed drive-ways on all sides (Abid and Lal, 2008). Nitrogen (N), potassium (K), and phosphorus (P) fertilizers were applied at the rate of 168 kg N ha^{-1}, 224 kg K ha^{-1}, and 112 kg P ha^{-1}, respectively. The experimental site has a long-term (25 years) average temperature and annual precipitation of 11.5 °C and 1039 mm, respectively.

2.2. Soil analyses

Soil core samples and bulk samples were obtained from middle of all 12 plots at 0–10, 10–20, 20–40, and 40–60 cm depths during 2011. The undisturbed soil core samples were taken with the steel-type core sampler (length = 5.0 cm, diameter = 4.8 cm) by using a double-cylinder hammer driven core sampler (Grossman and Reinsch, 2002). Soil pH and electrical conductivity (EC) were determined using 1:1 soil to water ratio (Glendon and Dani, 2002). Soil bulk density (BD) was determined by the core method (Grossman and Reinsch, 2002). Soil water retention was measured by using a combination of tension table and pressure plate extractors (Dane and Hopmans, 2002). The available water capacity (AWC) was calculated by subtracting the volumetric water content at the permanent wilting point (PWP: −1500 kPa) from that at the field capacity (FC: −30 kPa). Saturated hydraulic conductivity (K_{sat}) was estimated by using the van Genuchten–Mualem model and RETC computer code (van Genuchten, 1980; van Genuchten et al., 1991). Concentrations of SOC and total nitrogen (TN) were determined by the dry combustion method (900 °C) using a Vario Max CN Elementer Analyzer Inc. Hanau, Germany. A wet sieving procedure was used to determine the stability and size distribution of soil aggregates (Yoder, 1936). The mean weight diameter (MWD) was calculated and used as an indicator of soil structure. Soil particle size distribution was measured using the hydrometer method (Gee and Or, 2002). Microbial biomass carbon (MBC) was determined by the chloroform-fumigation extraction method (Vance et al., 1987). Soil temperature for each plot at 0–10 cm depth was recorded using a digital soil thermocouple temperature probe during 4 weeks after planting. Soil moisture content was determined gravimetrically for the same period.

2.3. Soil quality index assessment

The SQI was computed by using the scoring function analysis framework (Andrews et al., 2004; Karlen et al., 2001). Crop productivity was identified as the management goal in the study. The SQI was assessed by following a three step procedures: (1) identification of the minimum data set of indicators, (2) indicator interpretation, and (3) integration of the all indicator scores into one overall SQI value (Andrews et al., 2004) (Fig. 1).

For first step, SQI indicators were selected, in this study for soil physical properties, they were BD, K_{sat}, MWD, AWC, and mean soil temperature during 4 weeks after planting (Soil T), mean volumetric water content during 4 weeks after planting (Soil M). For chemical properties, pH, electric conductivity (EC), and SOC. Lastly, for biological property, MBC according to the appropriate indicator for the management goal in the study (Tables 1 and 2). Indeed, appropriate SQI indicators are those which influence the capacity of a soil to perform, and are sensitive to the final outcome. Therefore, indicators in this study selected on the basis of literature review, e.g., (Andrews et al., 2004), through discussions and consensus of the collaborating researchers, and research experience in Ohio.

In the second step, each indicator from the minimum data set was transformed into unit less combinable score ranging from 1 to 5 (where five represent the high level for indicators and one represent the low level). Table 1 shows the criteria for transforming indicators to scores accounting for their contribution to soil functions. In general, there are three general shapes of the standard scoring function for SQI (Karlen and Stott, 1994; Wymore, 1993). Increasing the level of the indicators when the quality of the soil is increasing, “the more is better” curve is used. Conversely, “the less is better” curve is suitable for decreasing the level of the indicators with the soil quality is decreasing. In addition, “the optimum” curve scores those indicators that have an increasingly positive association with soil quality up to an optimal level beyond which quality of soil decreases (Armenise et al., 2013) (Fig. 1, middle). After considering the appropriate curve type for indicators, the scoring functions chart were prepared for interpretation of SQI.

In the third step, the score values (ranging from 1 to 5) of each soil indicators are given specific weights ($W_{indicator}$) based on their contribution to agronomic productivity (Eq. (1)). The scores of each depth were also given specific weights according to the root density distribution of each depth (W_{depth}) (Eq. (2)) (Table 2). The individual scores were multiplied by weighting factors and combined into an overall SQI. Fig. 2 shows the procedure for the integration step for assessing SQI. The weightings were given subjectively; nevertheless, the soil physical, chemical, and biological properties are given almost equal weighting to emphasize the equal importance of these three categories of soil properties in their contribution to soil functions (weight 1). Each