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Effect of long term no-till and conventional tillage practices on soil quality

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ABSTRACT

Management systems influence soil quality over time. A randomized block design in 2 (tillage system) × 3 (crop rotation) factorial arrangement was laid-out to evaluate the impact of tillage and crop rotation (2002–2007) on soil quality. Conventional tillage and No-till were factored into continuous corn, corn–soybean, and corn–soybean–wheat–Cowpea systems. Ten soil cores were collected at 0–7.5, 7.5–15, 15–22.5 and 22.5–30 cm depths and analyzed for biological, chemical and physical parameters. The inductive additive approach was used to calculate biological, chemical, physical and composite soil quality indices. A significant impact of no tillage on different physical chemical and biological parameters was observed. The estimated soil quality index was significantly higher in soil under No-till than conventional tillage. Soil biological quality is a sensitive and consistent indicator of soil quality in response to management practices.

1. Introduction

Soil management practices are considered necessary to sustain crop yields to conserve or enhance soil quality (Aziz et al., 2009). A difference in management practices often result in differences in biological, chemical and physical properties of soil which in turn, result in changes in functional quality of soil (Islam and Weil, 2000; Aziz et al., 2009; Derpsch et al., 2010; Wolfarth et al., 2011; Celik et al., 2011; Ding et al., 2011). Inappropriate land uses and management systems lead to soil erosion, depletion of organic matter and other nutrients which results to permanent soil degradation and productivity losses (Ramos et al., 2011).

All internal and interrelated properties of soil (biological, chemical and physical) are significantly affected by reducing soil tillage (Thomas et al., 2007). Soils under No-till have greater storage of diverse plant biomass on undisturbed surface, which results in moist soil and low temperature with efficient microbial activity, better aggregate structure and considerable improvement in soil properties, particularly N content, SOM and SOC content, CEC (Cation exchange capacity) and decrease the C/N ratio (Madejon et al., 2009; Naudin et al., 2010; Derpsch et al., 2010; Moussa-Machraoui et al., 2010; Benitio, 2010; Celik et al., 2011; A'lvaro-Fuentes et al., 2012) compared to CT soils. No-till greatly enhances carbon accumulation within micro aggregates which in return form macro aggregates. This shift of soil organic carbon within micro aggregates is very beneficial for long term carbon storage in soil (Shan et al., 2010; Erkossa, 2011). No-till farming tends to reduce soil bulk density in the upper soil layer (Jina et al., 2011).

Since soil properties are interrelated, the challenge is to pinpoint and quantify core set of properties that can be used to confirm the usefulness of production technology for improvement of SQ. A large change in one property may not significantly affect others and small change in two or more soil properties may be individually insignificant but in concert with each other may have a significant impact on an agro-ecosystem (Reganold and Palmer, 1995).

Soil quality is hard to assess directly due to collective and multiple functional effects but can be evaluated from alterations in soil properties due to management operations. Conventionally, due to availability of easy analysis techniques soil quality studies basically focused on chemical and physical properties of soil (Larson and Pierce, 1994) but in recent years it was found that biological properties of soil act as early and sensitive indicators in response to alteration in management systems (Islam and Weil, 2000; Kennedy and Papendick, 1995). Consequently biological parameters together with soil chemical and physical properties are recognized to be necessary to assess SQ as affected by changes in management operations (Parkin et al., 1996).

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Soil organic matter (SOM) is historically considered as the indicator of soil quality because of its contribution in influencing soil biological, chemical and physical properties and crop yields (Islam and Weil, 2000). Others did not agree with SOM as the single indicator of SQ and suggested a combination of soil properties to be evaluated for assessment of soil quality (Islam and Weil, 2000). The particulate organic matter, active C, total N, microbial biomass, biological activities, enzymes, soil pH, cation exchange capacity, salinity, bulk density, amino sugar and soil aggregation are important indicators of dynamic soil quality because of their quick response to management practices (Islam and Weil, 2000; Wander, 2004; Aziz et al., 2009; Ding et al., 2011). As a dynamic component of SOM, microbial life of soil is often considered as a key indicator of SQ (Islam and Weil, 2000). The best quality soils are biologically more active and have a balanced population of microbes. Microbial biomass consists largely of primary decomposers that mineralize organic materials and release nutrients and energy by enzyme-facilitated metabolic systems. The threads of fungi and actinomycetes, bacterial mucigel and hyphae bind particles of soil together and enhance soil aggregation which result in more absorption of water, reduction in erosion, protects C in macroaggregates and maintain adequate pore spaces in soil (Kennedy and Papendick, 1995).

There are certain characteristics, particularly when considered together, that are good indicators of SQ. Larson and Pierce (1991) suggested that a small data set be used for measuring SQ and uniform methodologies and procedures be followed to measure certain changes in SQ. Monitoring of a select set of soil properties that can serve as indicators of change in SQ is possible and can yield useful information on trends in SQ (Dumanski and Pieri, 2000). Soil quality indicators should be a combination of biological, chemical and physical properties sensitive to management practices (Islam and Weil, 2000; Aparicio and Costa, 2007).

However there is still uncertainty remaining for the understanding of full impact of no-till technology on soil organic carbon (Ogle et al., 2012). This study was planned to evaluate the impact of tillage and crop rotation (2002–2007) on selected biological, chemical and physical properties as a minimum data-set of soil quality indicators and sensitivity of various soil quality indices to determine soil's overall functional capacity in agro-ecosystems.

2. Materials and methods

2.1. Study site

The study was conducted at Vanmeter farm of the Ohio State University South Centers at Piketon (39°02′30″N, 83°02′00″W), South-central Ohio, USA. On average, soil has pH 6.2, electrical conductivity 206.4 μS/cm, total porosity 44.6%, and contains 21, 55, and 24% sand, silt and clay, respectively at 0–30 cm depth

2.2. Field experiment and cultural practices

A field experiment with two (2) types of tillage (conventional tillage, CT and No-till, NT) and three (3) crop rotations (continuous corn, CC; corn–soybean, CS; and corn–soybean–wheat, CSW) in factorial arrangement of randomized complete block (RCB) design was established in 2002. Each treatment was replicated 3 times on $40 \times 100\ m^2$ plots.

2.3. Soil collection and processing

Prior to establishing the experiment, 18 composite soil samples were randomly collected from the entire field for baseline data using GPS guided systematic sampling in early spring (May) of 2002. Ten soil cores were collected from 30 cm depth in plastic tubes for each composite sample using an environmental soil probe (1.9 cm internal diameter). The soil cores were segmented at 0–7.5, 7.5–15, 15–22.5 and 22.5–30 cm, respectively in the laboratory. The segmented soils at each depth were mixed to get composite samples and gentle sieving was done through a 4-mm mesh to eliminate stones, plants roots and large organic substances. After sieving, the composite field-moist soil was divided into two equal parts and each sub-sample was placed in a separate Ziplock plastic bag. The soil from one sub-sample bag was passed through a 2-mm sieve and homogenized to measure antecedent soil moisture content and incubate for 7 d at room temperature (25 °C) to stabilize microbial activity. After stabilization, the field-moist soil samples were then used to measure microbial biomass and/or incubated for biological properties. Soil from the second bag was spread on a polyethylene sheet and air-dried at room temperature for 72 h and analyzed for selected chemical and physical properties. In early spring (May) of 2007, a total of 18 composite samples were taken (using GPS) from same soil locations and depth, processed and analyzed for evaluation of temporal (2002 vs. 2007) effects of tillage on soil properties.

2.4. Analytical methods

2.4.1. Soil biological properties

The soil microbial biomass (C_{mic}) was determined by following rapid microwave irradiation and extraction procedure of Islam and Weil (1998a, 1998b). The C_{mic} was calculated by using the following formula.

$$C_{mic}\left(\frac{\text{mg C}}{\text{kg soil}}\right) = \left(\frac{MWC_{ext} - UMWC_{ext}}{K_{ext}}\right)$$

The MWC_{ext} is the extractable C in microwaved soil, $UMWC_{ext}$ is the un microwave extractable C, the C_{ext} is extractable C of field-moist soil and K_{ext} is the fraction (0.241) of the C_{mic} extracted by 0.5 M K_2SO_4 (Islam and Weil, 1998a, 1998b).

Basal respiration (BR), as a measure of antecedent biological activity, was determined using 20 d in vitro static incubation of field-moist soil without any amendments (Islam and Weil, 2000). The estimation of BR rate was done by following formula

$$\text{BR rates}\left(\frac{\text{mg } CO_2}{\text{kg soil}}\right) = (CO_2\text{soil} - CO_2\text{air})20\,\text{d}$$

where CO_2 soil is the evolution of CO_2 during 20 d incubation of non-amended homogenized soil and CO_2 air is the ambient air CO_2 in a blank mason jar.

The qCO_2 i.e. catabolism of C per unit C_{mic} per day was calculated by following Anderson and Gray (1991).

$$qCO_2\left(\frac{\mu\text{g } CO_2}{\text{mg } C_{mic}/\text{d}}\right) = \left(\frac{\text{BR rates}}{C_{mic}}\right)$$

2.4.2. Soil chemical properties

The total organic carbon (C_{org}) and nitrogen contents were estimated using finely ground (125 μm sieved) soil with Elementar® CN dry combustion analyzer. Since the pH of the collected soil was <6.5, the total carbon content was considered as C_{org}. Active C (AC) based on $KMnO_4$ oxidation was measured on air-dried soil as described by Weil et al. (2003).

2.4.3. Soil physical properties

Standard core method was used to calculate bulk density (ρb) using mass per unit volume of soil. Particle size analysis was