Extended abstract

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A novel approach for on-farm assessment, prediction and management of SOC

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Abstract

Soil organic carbon (SOC) management is gaining importance in the grain producing regions of the Midwestern US. With the renewed emphasis on Soil Health by US agencies, farmers are realizing the importance and potential of SOC management. However, few tools and techniques are available for rapid, reliable, and in-field assessment and prediction of SOC stocks in response to different management practices. While the policy framework for SOC management may benefit from the vast availability of research data and complex simulation models, on-farm decision making lacks accessibility to these resources. The complex and highly technical nature of scientific information sometimes limits the ability of farmers to comprehend and make relevant decisions. We review the existing tools and techniques that have proven their superiority and applicability, and demonstrate a novel approach that integrates these tools and techniques into a decision framework for SOC assessment, prediction, and management at farm-scales.

Keywords: *Soil Organic Matter, Residue Management, Soil Quality, Active Carbon, Carbon Modeling*

Extended Abstract

Introduction, scope and main objectives

Maintaining a healthy and productive soil is the foundation of sustainable agriculture. The term “soil health” is gaining more prominence than the conventional concept of “soil quality”. Soil health not only relates to the physical, chemical and biological properties of soil, but also to its functionality and productivity (Doran et al. 1996). Assessment of soil health or overall soil quality typically involves a comprehensive assessment of soil physical, chemical, and biological properties. Commonly accepted indicators of soil health include a combination of: microbial biomass C and N, soil respiration, enzyme activity, macro-aggregate stability, water retention, infiltration, pH, Electrical Conductivity, Cation Exchange Capacity, potentially mineralizable N, plant available nutrients, and active and passive pools of soil organic matter (SOM) (Allen et al. 2011).

Soil testing laboratories serving farmers typically assess SOM using loss of mass on ignition method (Stevnson, 1994). The SOC can then be estimated based on the stoichiometric percentage of carbon (58%) in the SOM. Although several methods exist to quantify different fractions of SOM, the active fraction, and total SOC are considered to be composite indicators of soil health (Alllen et al. 2011). While the SOM is composed of both active and passive pools, each pool makes its particular contribution towards soil quality according to chemical composition and lability, physico-chemical stability, and turnover rates (Stevenson 1994). Maintaining the active (or labile) carbon (active C) pool is important to ensure greater biological diversity, and recycling of essential nutrients in soil. While, the more passive fractions are important with respect to buffering capacity, water and nutrient holing capacity of the soil.

Thus, a better understanding of both active- and passive pools of SOM induced by the impact of land-use changes may serve as a guide to evaluate overall soil health and soil quality.

An average farmer is limited by resources and technical knowledge to conduct a comprehensive soil health assessment. Furthermore, a soil health assessment report that involves numerous soil physical, chemical, and biological properties becomes difficult to interpret for farmers. The traditional fertility recommendations do not provide guidelines for managing, maintaining, and/or improving overall soil health by addressing any or many of these indicators. Thus, farmers are left to their own intuition and experience to make future management decisions with respect to agronomic practices as well as soil management. A framework that integrates a rapid, reliable field-assessment technique with a decision support tool that may help predict soil health/quality responses to future management practices is virtually non-existent. The objective of this study is to assess and demonstrate the feasibility of SOC, and its active fraction as a core indicator of soil quality, and develop a framework for a decision support tool for on-farm assessment, prediction, and management of SOC.

Methodology

A field test for active SOC:

A colorimetric test based on dilute (0.02 M) solution of slightly alkaline potassium permanganate ($KMnO_4$) that reacts with most readily available (active) forms of SOC is one of the most reliable, rapid and easy to adopt methods (Islam and Sundermeier, 2008; Weil et al. 2003). In the simplified method, slightly alkaline dilute solution of $KMnO_4$ reacts with most of the active fractions of SOM, changing the deep purple color of the solution to a light pink color. The lighter the color of the $KMnO_4$ solution after reacting with soil, the greater the amount of active C. The test involves mixing 0.02 M $KMnO_4$ with air-dry soil, 2 minutes of shaking, allowing 10 minutes for settling, and finally comparing the resulting color with a simple color chart calibrated for active C concentrations (Fig. 1).

Fig. 1 Field kit for in-situ active C test (https://go.osu.edu/SoilTestKit)

A tool for simulating SOC dynamics:

Over the past 30 years, several models, such as CENTURY, CANDY, DAISY, CQESTR, and Roth-C have been developed to assess C and nutrient turnover in agricultural systems (Jenkinson 1990; Smith et al. 1997). Most of these models are data intensive, require extensive training and local calibration, and were not designed to assess soil health. We developed the “OSU SOM Calculator”, a spreadsheet tool to predict long term SOM dynamics in response to different agricultural management scenarios (Shedekar, et al. 2016). The SOM Calculator consists of a user-friendly interface, with options to select crop rotation, management practices (tillage type, cover crops, drainage, manure application etc.), and residue removal rates. Based on these inputs, the calculator uses first order decay functions for calculating annual changes in SOM over short- and long-term. The effects of different management practices are incorporated using data from long-term research experiments, and a heuristic approach. The calculator further predicts active and passive fractions of SOM, CO_2 sequestration, and overall soil quality based on a soil health index.

Derivation of soil health index:

A soil health index (SH_{index}) is derived, using deductive and inductive additive approach (Aziz et al. 2013), that considers "higher or lower values of crop or soil properties (selected by a principal component analysis) are better indicators of soil health". Normalized values of each property are then summed and averaged into a single integrator, viz. SH_{index}. The SH_{index} ranges from 0 (extremely poor soil health) and 1 (Excellent soil health).

Results

Validation of field-test kit for active SOC:

The results of validation of field-kit for active C, compared to laboratory based protocol have been presented in detail by Islam (1997) and Weil et al. (2003). The $KMnO_4$-based laboratory technique was found to be to be rapid, highly reliable and repeatable. The active C measured using this test was found to be sensitive to management effects, and more closely related to biological soil properties, such as respiration, microbial biomass and aggregation. Furthermore, the field-kit for in-field assessment of active C showed a strong correlation ($R^2 = 0.98$) with the laboratory based protocol over a wide range of soils (Weil et al. 2003; and Islam, 1997). These results demonstrate the reliability of the field-kit for in-situ testing of active C.

Validation of SOM calculator:

The SOM calculator was tested for its prediction accuracy using data from 12 different field experiments, representing a range of soils, tillage practices, crop rotations, and management practices in Michigan, Illinois and Ohio (Shedekar et al. 2016). A comparison of predicted values of SOM versus the observed amounts showed a good agreement between the predicted and observed data, with a coefficient of determination (R^2) of 0.937 and other statistically derived performance indices (Nash-Sutcliffe efficiency 0.93, Root Mean Square Error 0.13, Percent bias -1.6).

Relationship between SOC, active C and soil health index:

We have developed empirical relationships between the SOC and SH_{index} and active C and SH_{index} for a range of soils, agronomic practices, and regions. A regression analysis based on more than 3000 soil samples from different regions shows that total SOC and active C can be used as reliable indicators of overall soil health and overall soil quality (Anonymous, 2016; Aziz et al. 2013; Weil et al. 2003). Furthermore, studies also suggest that a strong correlation exists between the total SOC and active C in most agricultural soils (Lucas and Weil, 2012). Thus, with a reliable estimate of total SOC and active C in a soil, it is possible to estimate the overall soil health.

Framework for a soil health decision support tool:

A framework is developed to integrate the field assessment technique for active C with the OSU SOM Calculator into a decision support tool that may assist in management of soil health (Fig. 2). The field-kit helps establish a reliable baseline with respect to active C, and total SOC. The SOM calculator can then help compare different future management scenarios and predict their effects on SOM dynamics over short- to long-term. The predicted quantities of total SOC and active C can then be used as input parameters in the empirical models for SH_{index} that can further estimate the overall soil quality and soil health. The final module of the system may help estimate the effect of change in soil quality and soil health on relative yields using regional empirical relationships between the SH_{index} and yields (Knight et al. 2013). The developed framework is currently being evaluated for the Midwestern region of United Sates, and the results of evaluation will be presented at the Global symposium on SOC.

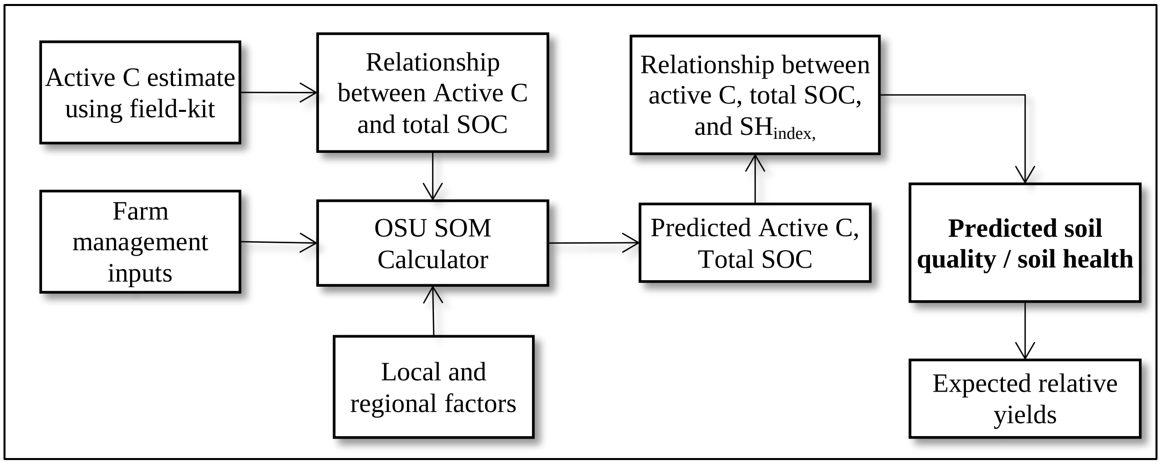

Fig. 2 Framework for a soil health decision support tool

Discussion

Unlike policy framework, the farm-scales management of SOC involves several local decision variables that relate to natural factors (e.g. soil type) as well as management options (e.g. tillage versus no-tillage, crop rotation, cover crops). Thus, a farm-scale decision support tool that takes into account these local factors becomes imperative. However, results of such regional/local systems may or may not be comparable at global scales due to multiplicity of input and output variables. The framework developed in this study provides an effective tool for management of SOC at local/regional scales, while the assessment technique (field-kit for active C) ensures its global relevance outside the system boundaries. The system can also be a valuable teaching tool for crop consultants and educators.

Conclusions

While the policy framework for SOC management may benefit from the vast availability of research data and complex simulation models, on-farm decision making lacks accessibility to these resources. The complex and highly technical nature of scientific information sometimes limits the ability of farmer to comprehend and make relevant decisions. This study demonstrates development of a framework that integrates science-based reliable techniques and tools for on-farm assessment, prediction and management of SOC. This framework can be applicable to any region after a regional validation of individual components.

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