Catena 125 (2015) 33–37

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

The importance of soil sampling depth for accurate account of soil organic carbon sequestration, storage, retention and loss

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ARTICLE INFO

Article history:
Received 28 April 2014
Received in revised form 7 October 2014
Accepted 9 October 2014
Available online 24 October 2014

Keywords:
Soil organic carbon sequestration
Rooting depth
Soil organic carbon stocks
Soil sampling depth

ABSTRACT

Soil organic carbon distribution within soil profile is highly influenced by management practices, especially tillage systems where soil environment is altered. Such changes in soil environment will affect soil carbon retention or accumulation in different layers of the soil profile. However, much published research in the area of soil organic carbon (SOC) sequestration focuses on shallow sampling depths within the 0–30 cm tillage zone when determining SOC stocks and sequestration. The objectives of this study are to quantify the SOC stock differences with depth between tillage treatments after 20 years and to determine the appropriate sampling depth when assessing SOC stocks as influenced by management practices. A 20-year moldboard plow (MP), chisel plow (CP) and no-tillage (NT) study was established with a maize–soybean rotation. The 75-cm root zone was sampled in 5-cm intervals to measure SOC stocks. The SOC sequestration, storage, retention and loss were determined for the 0–5 cm, 0–15 cm, 15–75 cm and 0–75 cm layers. The NT treatment did retain more SOC stock than the MP treatment to a 20 cm depth but the SOC stock of the 20–35 cm layer NT system was lower than the MP system. It is recommended that the depth of soil sampling has to include the entire root zone to accurately report SOC stock and the effect of tillage system on change in SOC.

1. Introduction

The traditional method of evaluating soil C dynamics under different tillage and cropping systems is collecting soil samples to determine changes in SOC stocks. One principle which needs to be kept in mind is depth of soil sampling, which can be affected by landscape position, cropping systems, tillage systems, drainage class, and other soil forming factors that dictate the change in SOC stocks in any particular field (Olson, 2013a). The interaction between root system and soil profile has profound impact on soil C accumulation, where root system can contribute to SOC stocks. Olson (2013a) defined SOC sequestration for a land unit and suggested the SOC sequestration process should result in a net depletion of CO_2 levels in the atmosphere. It is imperative that the SOC stock be measured beyond the tillage zone (0–30 cm) for the entire root zone depth to understand management practices such as tillage effects on SOC distribution when determining change in SOC stocks or sequestration rate. Generally, the interaction between, atmosphere, biosphere, and lithosphere affects nutrient vertical distributions in soil resulting in great chemical and physical gradients from surface to bedrock (Jobbagy and Jackson, 2001). Therefore, soil stratification is evident in soils and nutrient assessment including SOC are essential to have accurate account of management effects, such as tillage, on such distribution. It is well documented that type, thickness, and position of soil horizon can reveal the formation factors as well as management practices effects on SOC characteristics and distribution (Honeycutt et al., 1990; Marion and Schlesinger, 1985).

Schlesinger (2000) suggested soils might be a sink for atmospheric carbon with the application of conservation tillage and the establishment of native vegetation on abandoned agricultural lands. Luo et al. (2010) found that adopting no-tillage in agro-ecosystem has been widely recommended as means of enhancing carbon (C) sequestration in soils. However, results are inconsistent and vary from significant increase to a significant decrease. Yang and Wander (1999) suggested that reduced tillage and no-tillage (NT) practices generally concentrate SOC in surface few centimeters; however, the use of conservation tillage does not always result in increased SOC storage. Wander et al. (1998) found NT practices increased SOC and POM-C contents by 25 and 70%, respectively compared with conventional tillage at the surface (0–5 cm). This gain was at the expense of SOC at 5–17.5 cm depth, where SOC and POM-C decreased by 4 and 18%, respectively.

It is widely believed that soil disturbance by tillage is a primary cause of the historical loss of SOC in North America and that substantial SOC sequestration can be accomplished by changing from conventional plowing to less intensive tillage such as NT and conservation tillage. Different sampling protocol can lead to different estimates of SOC stocks. Sampling and SOC analysis of the plow layer, tillage zone or management zone have often lead to different findings for the 0–20 cm layer

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http://dx.doi.org/10.1016/j.catena.2014.10.004
0341-8162/

than would have been determined if the root zone or a 1 or 2 m depth had been sampled and tested (Olson, 2010). This is especially true when depth of tillage is sufficient to mix the surface layer with part of the subsoil layer and to a depth below the sampling zone. In these cases the SOC rich surface layer can be buried below the shallow sampling zone. When measuring SOC sequestration, storage or retention and loss it is important to include all the SOC in the root zone, which is commonly to a depth of 1 or 2 m unless there is a root restrictive layer present, such as a very dense horizon, fragipan or bedrock. Tillage systems can influence SOC distribution, storage or retention and loss in the surface and subsurface layers (Olson, 2013a; Olson et al., 2014). Deep tillage, such as moldboard or chisel plow, can significantly alter SOC distribution in the root zone. Soil inversion by moldboard plowing can translocate surface soil SOC to lower depths.

Most soil plots in SOC sequestration research studies have commonly been sampled to a 20-cm depth (ranges between 6 and 30 cm) including the North American regional SOC sequestration rate studies (Franzluebbers, 2010; Franzluebbers and Follett, 2005; Gregorich et al., 2005; Johnson et al., 2005; Liebig et al., 2005). West and Post (2002) reviewed 137 paired studies and showed more SOC stock was stored in NT than MP, but only considered, SOC measured in the top 15 or 30 cm. Kumar et al. (2012) sampled soils to 40 cm depth at two Ohio plot areas but only reported total gain in SOC for the 0–20 cm surface layer. Olson (2013b) calculated the gain or loss in SOC stock at these two Ohio plot areas for the 20–40 cm layer and found SOC stock gain for the combined 0–40 cm layer was only half as much as the reported SOC stock for the 0–20 cm layer at one site and slightly less at the other site. Clearly, the depth of soil sampling and testing did affect the SOC gain findings.

Most soil sampling techniques use distance from the soil surface as a primary metric. The soil surface, however, is a reliable datum only for measurement of C concentration characteristics directly related to distance from the soil surface at the time of sampling (Wuest, 2009). Deep SOC profiles differ between the tillage treatments of interest. Deeper sampling will not completely overcome effects caused by bulk density variations and resultant change in soil surface elevation except when the SOC constituent is sampled deep enough to be approaching zero in the lower layer (Lee et al., 2009). Equivalent soil mass (mass-depth) instead of linear depth can be used to correct for tillage treatment differences in soil bulk density, allowing more precise and accurate quantitative comparison of SOC constituents (Doetterl et al., 2012; Ellert and Beltany, 1995; Lee et al., 2009; Wuest, 2009). Sampling soils to the bottom of the root zone where the SOC concentration is nearly zero is recommended. Soil layers with only trace amounts of SOC present do not significantly change the total SOC stock in the soil profile (Soil Survey Staff, 1968).

Kreznor et al. (1989; 1990; 1992) measured the thickness of the A horizon, the root zone and depth to parent material on a hillslope landscape prior to accelerated erosion. Fig. 1 shows how the A horizon, root zone thicknesses and depth to parent material vary with landscape position. The A horizon and root zone were thickest on the interfluve and toeslope. If one had sampled only the 20-cm layer the SOC located below that depth on the interfluve, shoulder, footslope and toeslope would not have been included. In addition, the root zone below the 20-cm layer also contained significant SOC for all landscape positions (Kreznor et al., 1989, 1990, 1992).

In long-term studies, 20 to 50 years, one tillage practice can increase the SOC stock in plow layer while at the same time decreasing it in the subsoil when compared to other tillage treatments and pre-treatment SOC stocks (Olson, 2010; Zinn et al., 2005; Sa et al., 2001a, 2001b). Deeper sampling of root zone or to a 1 or 2 m can change the SOC stock and sequestration rate findings for the same soil profile if the soil had only been sampled and tested to a 20 cm depth. In a long-term tillage study in Illinois (Olson, 2010), the NT system showed SOC stock increase in the upper 0–5 cm layer, but there was a SOC loss within the 5 to 75 cm subsurface layer. The SOC stocks need to be accounted for in the root zone in order to assess tillage system effects and plant contributions to SOC stock change. Much of the contradiction in SOC stock and SOC sequestration findings (Olson, 2013a; Olson et al., 2014) is partially a result of differing soil sampling depths/protocols. The objectives of this study are to quantify the SOC stock differences as affected by depth between tillage treatments after 20 years and to determine the appropriate sampling depth when assessing SOC sequestration, storage, retention and loss.

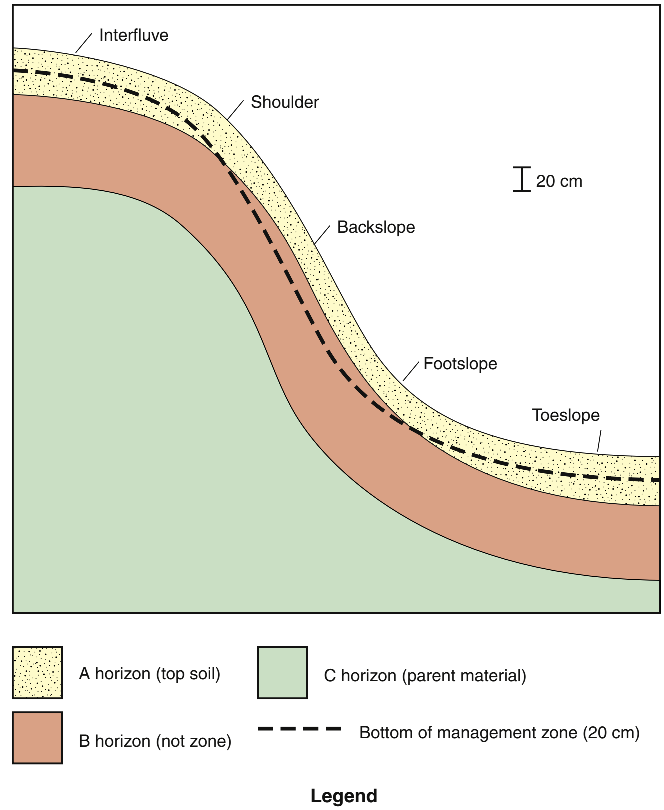

Fig. 1. A horizon thickness, root zone thickness and depth to parent material is shown for a hillslope landscape.

2. Methods

2.1. Experiment site and field treatments

A long-term tillage experiment was started in 1989 at the Dixon Springs Agricultural Research Center in southern Illinois. The soil at the study site was a moderately eroded phase of Grantsburg silt loam (fine-silty, mixed, mesic Typic Fragiudalf) (Soil Survey Staff, 1999) with an average depth of 64 $\pm$ 6 cm to a root-restricting fragipan. The area had an average slope gradient of 6%. Starting with maize (*Zea mays* L.) in 1989, maize and soybean [*Glycine max* (L.) Merr] were grown in alternate years. The experimental design was two Complete Latin Squares and each square having three rows and three columns (Cochran and Cox, 1957) which allowed for randomization of the tillage treatments no-tillage (NT), chisel-plow (CP), and moldboard-plow (MP) both by row (block) and by column. This replication was used to control random variability in both directions. Each tillage treatment was randomized six times in 18 plots with a size of 9 m $\times$ 12 m. The columns were initially separated by 6 m buffer strips of sod. Later the buffer strips were planted to NT maize and soybeans to reduce deer damage. An electric fence was later used to protect the crops in the plot area. There was a 60 m wide filter strip between the plot area and the waterway.