User Communities – Land Managers

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The role of soil C in conventional and regenerative agricultural systems. Land managers measure soil dynamic properties to inform future management decisions and to understand the consequences of past management actions on soils (Doran and Jones 1996). In conventional systems, measurement has typically prioritized plant available (soluble) forms of nutrients such as nitrogen, phosphorous and potassium. When soil C is measured in conventional systems, it is typically done to inform concentration of fertilizer and pesticide application (Table 1; Brady and Weil 2002; Wauchope et al 2002). This approach has dominated soil testing and fertilizer recommendations since the 1940s and 1950s, and has guided university based agronomy research (Drinkwater and Snapp, 2007).

In contrast, soil C, as soil organic matter, has explicitly been at the core of what might be called organic and regenerative systems since their entrance upon the agricultural scene as distinct production strategies. In 1911, Fredrick King (King 1911), reported the central role of the systematic recycling of organic matter in sustaining Chinese agricultural soils for millennia. Sir Albert Howard, considered by many to be the father of the modern organic farming movement, rooted his newly systematized composting methodology in the organic matter recycling practices of the traditional farming systems he studied while working as an agricultural mycologist in colonial India (Howard 1943). On the heels of the dustbowl years, Edward Faulkner (1943) wrote passionately on the folly of the use of the moldboard plow, most particularly on its negative effects on soil organic matter. Ironically, while soil organic matter historically lies at the heart of organic farming, the USDA National Organic Program today contains virtually no mention of the central role of organic matter in soil fertility or agricultural sustainability (CCOF 2015).

There is an increasing awareness of the detrimental effects of several conventional management practices on soil health. For example, high levels of nitrogen fertilizer application results in the decoupling of carbon and nitrogen cycles (Asner et al. 1997) and leads to evolutionary changes in critical plant: bacterial mutualisms (Weese et al. 2015). In addition, long-term use of nitrogen fertilizer has been shown to decrease the soil's ability to supply N, and degrades soil C (Mulvaney *et al*. 2009).

Environmental problems, such as the annual "Dead Zone" in the Gulf of Mexico, are directly tied to overuse of chemical fertilizers. A U.S. Geological Survey study showed that nitrate concentrations in the Mississippi River and its' tributaries have not changed from 1980 to 2008, and have even increased in some areas (Sprague *et al*. 2011). As Drinkwater and Snapp (2007) write, "Despite more than 30 years of concentrated effort, mass balances indicate annual N and P inputs consistently exceed harvested exports by 40 to ≥60% resulting in substantial losses of these nutrients to the environment (Bolland and Gilkes, 1998; David and Gentry, 2000; Galloway and Cowling, 2002; Van der Molen *et al*., 1998)." More recent work by Van Meter *et al*. (2016) showed a significant amount of soil organic N (SON) that is accumulating in soils will impact water quality into the future, with a lag time of 35 years for 99% of legacy SON.

Effects of long-term tillage practices results in poor aggregate stability, reduced microbial activity, and higher erosion potential (Lal 1993, Karlen et al. 1994). As a result, there is a growing interest in agricultural management practices that create and maintain soil fertility through building soil organic matter. Managing for soil C recognizes and prioritizes the role that soil organic matter plays in soil stability and fertility and bring soil C measurement to the forefront of measurement and monitoring priorities.

Many innovative producers across the U.S. manage for soil C, and thus have been able to reduce fertilizer and other inputs as their soil improves. This has been done through crop intensification and diversification (e.g. cover crops, adding new cash crops), reducing soil disturbance (e.g. continuous no-till), keeping the soil covered with plant and/or plant residues, and adding livestock to the land. What is notable about these producers is that they have typically *not* relied on traditional extension and land grant institutions to help them make these changes, but have relied on their own on-farm experimentation, or learned from other innovators. While this group of producers has been willing to take risks to change their practices, the challenge remains of how the "vast middle" group of producers will move forward to improve soil C. This is where new soil C measurement tools can give these producers confidence to make changes.

Traditional soil testing methods were developed for agricultural systems that did not fully take into account the role of soil C and its' role in nutrient cycling. As soil C increases, innovative producers have discovered that these traditional soil tests provide less, or even inaccurate, information about soil nutrient availability. Dr. Dwayne Beck of South Dakota State University, who manages the Dakota Lakes Research Farm, has noted that at an Olsen P of 5 ppm they get no crop response from adding P fertilizer (M. Henning, personal communication, June 18, 2015). 5 ppm is on the low end in a soil test, and P fertilizer is typically prescribed by land grant universities and soil testing companies at this level. The Dakota Lakes farm is highly innovative, using continuous low disturbance no-till, high cash crop diversity, cover crops, and more recently livestock, to improve soil C and thus improve nutrient cycling.

Challenges associated with measuring soil C for land managers. For managers, the decisions of what, where and when to measure soil C can be daunting. Regardless of whether a producer uses a conventional or sustainable/regenerative approach to farm management, navigating the suite of measurement platforms that are available and interpreting results is daunting. Table 2 provides examples of soil measurement services, tools and frameworks.

Soil carbon builds over the course of years to decades, but management decisions are made on the scale of days to seasons. Thus, managers who manage for, and measure, soil carbon do not have feedback on the same timescale that management decisions are made. This can make corrections to management slower than desired.

Soil carbon concentration varies over small spatial scales, thus the number and location of samples required are not always easy decisions to make. Spatial heterogeneity in the response of soil C to management creates special challenges when the goals of monitoring are to calculate total tons of carbon per unit area or measure short term fluxes in soil carbon; the cost and effort needed to for these measurements likely preclude them as a requirement for participation in cap and trade markets because the cost of measurement would outweigh the payment, at least for some land types and uses such as arid rangelands (Booker et al. 2013).

Research priorities for land managers. Here, we recommend three areas of research that can improve the utility of soil C measurement for land managers.

1. Setting soil C targets or goals. An essential first step in management is setting the goal, and producers are challenged by setting soil C goals that are appropriate for their soil and geography. Research that is focused on identifying biologically meaningful targets will be important for farm and ranch planning.
2. Guiding reduction of inputs as soil C increases. New soil testing methods are needed that focus on helping producers track and understand changes in soil C, which may help give producers confidence to "take their reward," e.g. reduce fertilizer inputs, based on technology that is measuring the impact of improvements in soil health. This technology should be commercially scalable so that it is widely available. New methods should be easy to use in terms of soil sampling procedures, and results need to be useful in informing time sensitive management decisions such as fertilizer rates.
3. Linking increases in soil C to productivity, yield and/or profits. Communicating the benefits of managing for soil C may help move adoption from the early innovators to more mainstream producers. To this end, collecting data that demonstrates improvements in productivity, yield, and/or profits will be valuable.

Table 1: Common goals for measuring soil C according to the user audience and the agricultural system.

User Audience	Goals for Conventional Systems	Goals for Sustainable/Regenerative Systems
Internal (within-farm management)	Guide pesticide & fertilizer application	• Track soil building or loss • Guide reduction of fertilizer applications
External (communicate with others)	• Avoid increased regulation?	• Demonstrate effectiveness of practices • Marketing • Payment for ecosystem services

Table 2: Examples of soil measurement tools, services and frameworks that measure soil C or multi-proxy indicators.

Tool	Measurements	Guide Input Decisions?	Commercial?
PLFA	Taxonomic groups of soil microbes	Not directly	Yes
Direct Counts	Types and numbers of soil microbes.	Not directly	Yes
Haney Test[1]	Soil respiration, water-extractable carbon, C:N ratio, organic and inorganic nutrient pools	Yes	Yes
Solvita CO_2 Burst	CO_2 soil respiration	Yes	Yes
Solvita Labile Amino-Nitrogen (SLAN)	Organic nitrogen reserves	Yes	Yes
NRCS Soil Quality Test Kit Guide	Multi-proxy measurements such as bulk density, aggregate stability, and water infiltration	No	No
National Resource Inventory			No
Cornell Soil Health Test	Physical, chemical, & biological properties of soil.	Yes	No

[1] We list this test here because it is commonly offered by commercial labs but recognize that there is lots of debate over its utility.

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