

Title: The effect of tillage on oxidation of soil organic carbon in organically-managed soil.

Principal Investigator(s) and Cooperator(s): Claudio Stöckle, Stewart Higgins, Lynne Carpenter-Boggs, Andy Bary, Craig Cogger and Doug Collins.

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Abstract: Organic agriculture uses tillage for several purposes including incorporation of organic inputs. Tillage also speeds oxidation of inputs and soil organic carbon (SOC). In order to understand and model the potential of organic inputs to change total SOC, we need to better characterize the effect of tillage on the simultaneous mineralization and oxidation of inputs and SOC. We will use the natural abundance of ^{13}C ($\delta^{13}\text{C}$) in corn-based manure to facilitate differentiation of input and SOC oxidation in response to tillage in organically managed soil.

We will impose tillage/no-tillage treatments and measure $\delta^{13}\text{C}$ over the growing season in non-vegetated plots that were amended with manure in 2011. Also in 2012, a repeat of the experiment will be established. By enhancing models of input and soil C turnover and sequestration, we address BIOAg Priority Areas of fertility, soil quality, and organic wastes.

Project Description

Introduction/Literature Review

The maintenance of high C-content soils is thought to be one of organic agriculture's primary environmental services. Incorporation of organic C into the soil affects soil organic carbon (SOC) content (Rasmussen and Collins, 1991; Paustian et al., 1992; Larson et al., 1972), but SOC equilibrium levels may not be reached for several decades (Rasmussen and Parton, 1994). Since lasting changes in SOC take so long to materialize, claims of carbon sequestration under organic management tend to be validated by long-term experiments, e.g., Teasdale et al., (2007). We are in the process of refining and validating a computer simulation model, CropSyst that will help predict the carbon footprint of organic farms and reduce the need for long-term experimentation. Organic agriculture often depends heavily on tillage for weed control and general ground preparation (Teasdale et al., 2007), but tillage enhances the oxidation of the very SOC that organic agriculture strives to preserve (Huggins et al., 1998; Huggins et al., 2007). Any valid simulation model, if it is to be used in the context of organic farm management, needs to account for the effect of tillage on SOC oxidation. In a recent study using CropSyst (Stockle et al., 2010) the tillage effect on SOC oxidation was simulated by setting upper and lower boundaries for the effect, and then presenting the results of the simulation as lying within the range dictated by these boundaries. The authors of the study noted, "There is enough uncertainty associated with the effect of tillage on SOC decomposition to justify the use of boundaries as done in this study." The values they chose, however, were "*reasonable but arbitrary* lower and upper boundaries of tillage effects on SOC oxidation rates" (Stockle et al., 2010).

We propose to advance beyond "reasonable but arbitrary" by developing an accurate method to measure the fate of SOC in response to tillage in organic systems within a relatively short time frame. Once we have reliable data concerning the tillage effect on SOC decomposition, models of the effect can be more appropriately parameterized to predict accurately the change in SOC. Tillage intensity and the type of tillage, along with amendments, soil type, SOC content and

climate all affect the response. The change in SOC has been modeled as (Kemanian and Stöckle, 2010)

$$\frac{dC_S}{dt} = h \left[1 - \left(\frac{C_S}{C_X} \right)^n \right] C_i - f_e f_t k \left(\frac{C_S}{C_X} \right)^m C_S \quad [\text{Eq. 1}]$$

where C_S is SOC, t is time, h is the carbon input from humification, C_X is the saturation carbon content (from Hassink and Whitmore, 1997), n and m are empirical constants, k is the maximum C_S decomposition constant, f_e is the environmental effect on SOC decomposition and f_t is the SOC decomposition rate adjustment factor due to tillage. f_t is calculated as

$$f_t = 1 + [Fcx + (Fsx - Fcx) \exp(-5.5 f_{clay})] [1 - \exp(-0.025 CSDR)] \quad [\text{Eq. 2}]$$

where Fcx = maximum adjustment factor for clay soil, Fsx = maximum adjustment factor for sandy soil, f_{clay} = soil clay fraction and $CSDR$ = cumulative soil disturbance rate (Stöckle et al., 2010). Although this adjustment factor, f_t , has proven useful, the parameters that determine its value are poorly characterized.

In organic systems nutrients are often supplied in organic amendments, and the oxidation of these amendments confounds the measurement of the effects of tillage on *bone fide* SOC. This study will differentiate amendment and SOC oxidation in response to tillage by taking advantage of natural differences in the ratio of natural stable carbon isotopes ^{12}C and ^{13}C ($\delta^{13}\text{C}$) in different plant types. The photosynthetic pathway of plants discriminates against ^{13}C , but corn and other C4 plants accumulate relatively more ^{13}C than do C3 plants. Because SOC in this region is primarily derived from C3 plants, its $\delta^{13}\text{C}$ or ^{13}C “signal” is very different than that of corn or the manure of corn-fed animals. We can measure very small differences in $\delta^{13}\text{C}$ using isotope ratio mass spectrometry. So, if we introduce corn-based carbon into the soil, we can accurately track decomposition of both the amendment and SOC in response to tillage. The natural abundance of ^{13}C has been used effectively to quantify the sources of changes in SOC within a relatively short time frame (Collins et al., 2010). Furthermore, $\delta^{13}\text{C}$ has been shown to be a more sensitive measure of SOC dynamics than total C (Lynch et al., 2006).

Objectives

Our goal is to improve the accuracy and relevance to organic systems of the tillage factor in CropSyst. This requires appropriate parameterization for the equation used to determine the tillage factor, f_t , for calculation of the SOC decomposition rate. Our objective for this proposal is to characterize the decomposition of SOC and manure amendment in organically managed soil using natural ^{13}C abundance. The technique will form the basis of a larger effort to determine the effect of tillage on the decomposition of SOC for a range of soil types and cropping systems.

Procedures

To explore the technique of using ^{13}C to assess SOC decomposition, we will measure the fate of ^{13}C in non-vegetated plots amended with corn-based manure in 2011. We need to determine whether the fate of ^{13}C provides a quicker and more sensitive assessment of SOC decomposition than the conventional method of measuring total SOC. We therefore will process samples to measure both $\delta^{13}\text{C}$ and total C. The plots are located at WSU Puyallup Research & Extension Center, a BIOAg Learning Site. The plots are 5 x 15 feet, arranged in a randomized complete block experimental design with 4 blocks. Each block contains 2 plots, one of which received no manure and the other of which received 130 lbs of manure collected fresh from Werkhoven Dairy in Monroe, WA. About 70% of these cows’ diet was corn-based. The manure was worked into the soil to a depth of 6 inches with a spader. In 2012 we will impose tillage/no-tillage treatments on these plots and assess $\delta^{13}\text{C}$ at 6 times during the growing season. Half of

each plot will be rototilled to a depth of 6 inches in late April or early May which is when the plots ordinarily could be seeded to a crop. The soil disturbance rating for rototilling will be calculated from NRCS (2002) as described by Kemanian and Stöckle (2010). Also in 2012, another set of plots will be amended with the corn-based manure to provide a repeat in time of the entire experiment.

At each of the 6 sampling times, 6 cores will be removed from the tilled portion of each plot and 6 from the non-tilled portion. These 6 cores will be composited, dried at 45°C, sieved to pass 2 mm, ground and finally analyzed. Total C will be determined by dry combustion on a Costech elemental combustion system. Soil $\delta^{13}\text{C}$ will be analyzed using a Thermo Finnigan isotope ratio mass spectrometer. In addition to these soil samples, $\delta^{13}\text{C}$ will be measured for the manure, for C_3 crops and for nearby undisturbed native soil.

The changes in SOC from various sources will be assessed as described by Collins et al (2010). The changes will be assessed both in terms of total C and $\delta^{13}\text{C}$. For brevity, only the $\delta^{13}\text{C}$ approach is presented below – calculations from the two perspectives are analogous. The change in SOC due to cropping the plots will be assessed as

$$C \text{ from cropping (\%)} = \frac{\delta^{13}\text{C}_{\text{farmed soil}} - \delta^{13}\text{C}_{\text{native soil}}}{\delta^{13}\text{C}_{\text{crop}} - \delta^{13}\text{C}_{\text{native soil}}}$$

This measure of soil carbon from cropping will be other than zero only if humification caused a measureable change in the ^{13}C signature, which is unlikely. We include these measurements because if there is a measureable change, we will then be able to separate the effects of tillage on decomposition of carbon that was in the soil prior to amendment with manure from the decomposition of the carbon in the manure.

The change in SOC from manure will be assessed for both tilled and non-tilled treatments as

$$C \text{ from manure (\%)} = \frac{\delta^{13}\text{C}_{\text{amended soil}} - \delta^{13}\text{C}_{\text{non amended soil}}}{\delta^{13}\text{C}_{\text{manure}} - \delta^{13}\text{C}_{\text{non amended soil}}}$$

Once the remaining manure-derived C is known for each sampling time, the decay constant, k , for the respective tillage treatments can be calculated from

$$C_S = C_0 e^{-kt}$$

Where C_S is the amount of remaining C at time t , C_0 is the amount of manure-derived C at time zero and t is time (Collins et al., 2010; Huggins et al., 1998).

Now with k known, estimates of the humification rate, h , can be obtained from (Kemanian and Stockle, 2010; Huggins et al., 2007)

$$\frac{dC_S}{dt} = hC_0 - kC_S$$

Finally, everything needed to solve for f_t in Equation 1 is available except f_e , which is calculated as a function of soil water potential and temperature (Kemanian and Stockle, 2010). With estimates of f_t in hand, the parameters in Equation 2 can be adjusted on the basis of biological responses, rather than on best guesses. Modeled predictions of tillage impacts on SOC

will then have the potential to be reasonably precise, removing the need to report a range of values.

Expected Outputs

Expected outputs include estimates of the respective carbon decay constants (k) for pre-treatment, C₃-derived SOC and post-treatment manure-derived carbon for both the tilled and un-tilled treatments. We also expect to obtain estimates of the humification rate constant (h) for manure-derived carbon. With these parameters available, we will be able to derive the SOC decomposition rate adjustment factor due to tillage, f_t , for the Puyallup soil and determine whether examination of $\delta^{13}\text{C}$ is a reasonable alternative to long-term experiments for the characterization of tillage effects on SOC decomposition. CropSyst will be refined to provide reasonable estimates of the effect of tillage on SOC decomposition. A proposal to fund a more extensive research project would be prepared in the fall of 2013 (see Leverage Plan, above). In the next 3 years, this work would be utilized in at least one national conference presentation and two manuscripts.

Expected Impacts, -Short-term, -Intermediate-term and -Long-term

In the short term, the knowledge gained would either confirm or refute that the use of ^{13}C in studies of SOC dynamics can reduce the time required to obtain meaningful results in the context of SOC decomposition. The study will indicate the effect of tillage on the residence time of SOC and amendment C. Incidentally, the results would quantify changes in SOC that have occurred over time at the Puyallup BIOAg Learning Site. A successful outcome to the proposed work would lay the groundwork for a more precise determination of the impact of tillage on oxidation of SOC. This result would be important not only for organic farm management – it would be every bit as valuable for conventional farm management. One benefit of a successful short-term outcome would be the full-blown research to determine the effect of tillage on SOC decomposition for a range of tillage intensities and soil types.

Within 5 years growers and scientists would be able to obtain modeled estimates of SOC change that reflect accurately the impact of tillage on SOC. Given the pivotal role of tillage on SOC dynamics (Huggins et al., 1998) accurate model predictions that incorporate tillage effects would influence farm management behavior. In the intermediate-term, incorporation methods, timing, and/or materials will shift to maximize benefits to crop production, enhance retention of SOC, and improve environmental services. The multiple benefits of SOC retention are well known, though accumulate over the long term.

Evaluation Plan

We will know the project was successful by analyzing the data from 3 perspectives. First we will determine whether $\delta^{13}\text{C}$ effectively differentiates amendment and SOC oxidation within two cropping seasons. Second, we will determine whether SOC oxidation was influenced by tillage. Finally, we will determine whether estimates of SOC oxidation based on $\delta^{13}\text{C}$ were any better than those based on total C. As noted above, in other studies results based on $\delta^{13}\text{C}$ were more sensitive than those based on total C, so the use of $\delta^{13}\text{C}$ should decrease the amount of time required to collect data to be used for model parameterization.

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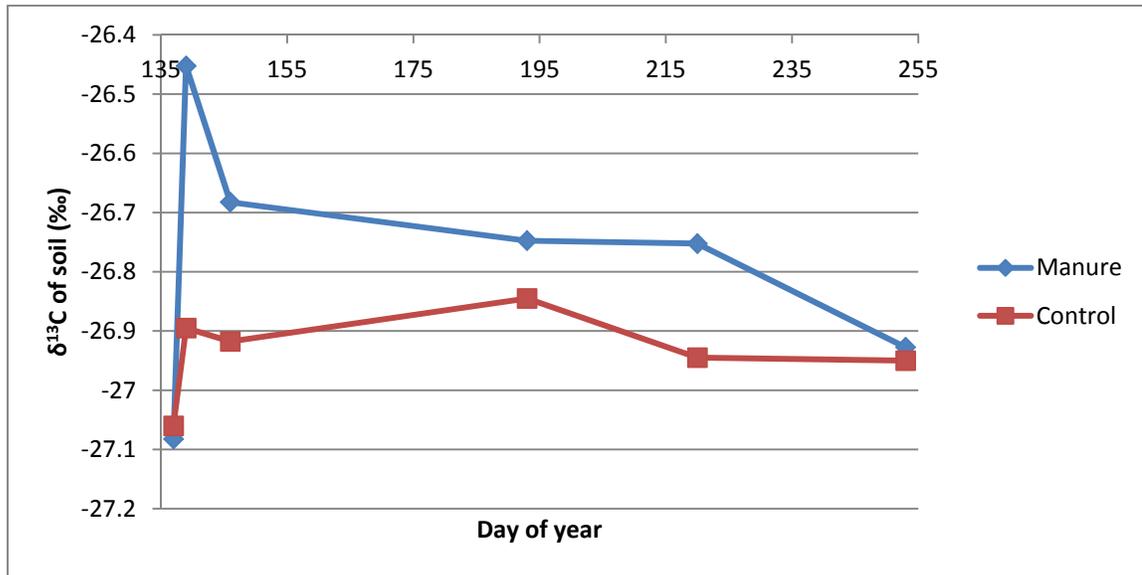
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Outputs

- Work Completed: Soil samples were collected from untreated control plots and plots that had been amended with corn-based manure in 2011. In May of 2012, another set of control plots and plots amended with corn-based manure were established. Each treatment was replicated 4 times. These newly established plots were maintained weed-free for the 2012 growing season. The plots were sampled May 15 (prior to tilling-in manure), May 17 (immediately after manure was tilled in), May 25, July 11, August 13 and September 8. Soil samples were processed for $\delta^{13}\text{C}$ by WSU's Stable Isotope Core Laboratory. Data were analyzed using the MIXED Procedure of SAS (Littell *et al.*, 2006).

In 2011 $\delta^{13}\text{C}$ did not differ significantly between control and manure-amended soil at the end of the growing season (data not shown). Data from 2012 are presented in Figure 1. From the time the manure was applied until July 11, the manure-amended soil consistently had a less negative $\delta^{13}\text{C}$ than did the control soil, although the difference was statistically significant only on May 17 which was immediately after incorporation of the manure. By the end of the growing season, even the trend had disappeared – there was virtually no difference between the two treatments with respect to $\delta^{13}\text{C}$ (Fig. 1).

Figure 1. $\delta^{13}\text{C}$ of soil sampled on six dates in 2012 at the WSU Puyallup Research and Extension Station. Soil was either left untreated or was amended with fresh, corn-based, dairy manure on day 139. Within a date, there were no significant differences between the treatments except on day 139 when the $\delta^{13}\text{C}$ of the manure-amended soil was significantly higher than the control soil.



- Publications, Handouts, Other Text & Web Products: No publications have been produced to date. A detailed final report will be prepared by the end of 2013.
- Outreach & Education Activities: None planned.

Impacts

- Short-Term: The use of corn-based manure to study tillage effects on SOC dynamics under our soil conditions was shown by this study not to be feasible. The $\delta^{13}\text{C}$ of the manure (-20.93‰) was not high enough to be retained for the period of time necessary to meet our objectives. Furthermore, the relatively high soil organic matter (~ 3%) in our study soil overwhelmed the $\delta^{13}\text{C}$ signature of the added carbon in the manure. Only about 4% of the total C in the top 30 cm of soil was added in manure. This technique might be feasible in low-SOM soil that had been cropped with C_4 species for many years, but these conditions are relatively rare in the Pacific Northwest.
- Intermediate-Term: No impacts. The expected results that would have warranted a major research proposal (see Project Description above) did not materialize.
- Long-Term: No impacts.

Additional funding applied for / secured

None

Graduate students funded

Although we expected to support a graduate student for this study, the negative results precluded inclusion of this research in a graduate program.

Recommendations for future research

Apparently, for this work to succeed, it needs to be done on soil that has a relatively long history of C₄ crop production. The question of how tillage affects the oxidation of SOC is important enough to warrant spending time trying to locate a suitable study site. But the idea of following the fate of ¹³C from corn-based dairy manure was, unfortunately, unsuccessful.