BIOAg Project 3076-8993 Second Final Report

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

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KEY WORDS: $\delta^{13}C$, diary manure, C_4, SOC

ABSTRACT SEE REPORT 6-26-13

PROJECT DESCRIPTION SEE REPORT 6-26-13

OUTPUTS

- Work Completed: SEE REPORT 6-26-13. ALSO, A MANUSCRIPT HAS BEEN PRODUCED (SEE BELOW) FOR SUBMISSION TO A PEER REVIEWED JOURNAL. THIS MANUSCRIPT WILL BE SUBMITTED BEFORE THE END OF JANUARY, 2014.
- Publications, Handouts, Other Text & Web Products: See manuscript below.
- Outreach & Education Activities: None

IMPACTS

- Short-Term: We have knowledge of the decomposition dynamics of fresh dairy manure in soil. This information can be immediately used in ongoing modeling efforts to asses environmental services of organic farming.
- Intermediate-Term: When published, the results will be available to the general scientific community for use in assessing decomposition of cow manure.
- Long-Term: Future projects by other researchers will be more aware of the advantage of using naturally occurring stable isotopes to assess decomposition of particular carbon pools within soil containing complex mixtures of carbon from various sources.

ADDITIONAL FUNDING APPLIED FOR / SECURED NONE

GRADUATE STUDENTS FUNDED SEE REPORT 6-26-13.

RECOMMENDATIONS FOR FUTURE RESEARCH SEE MANUSCRIPT BELOW AND REPORT 6-26-13.

Decomposition of dairy manure assessed by monitoring natural abundance of ^{13}C in organically-managed soil.

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Key words: $\delta^{13}C$, C4, decay constant, SOC

Abstract: Organic agriculture uses cattle manure as a soil amendment to provide nitrogen and organic carbon. If the cattle from which the manure came had a high proportion of corn in their diet, the manure may have a sufficiently distinct $\delta^{13}C$ composition from that of the parent soil. The difference in $\delta^{13}C$ between the amendment and the soil will allow researchers to follow the fate of the manure-derived carbon in the soil. We applied fresh dairy manure from corn-fed cows to plots in western Washington state to assess the effect of tillage on the oxidation of organic carbon and to characterize the decomposition of the applied manure under field conditions.

By the end of the season, not enough manure-derived carbon remained in the soil to provide a sufficient $\delta^{13}C$ signature to allow an assessment of the effect of tillage on organic C oxidation. The decomposition rate constant for the manure was, however, determined to be 0.0642 d^{-1} in soil under dryland field conditions. With this rate of decomposition, only about 1% of the manure-derived carbon remained in the soil after 10 weeks.

The use of native abundance of carbon isotopes is a useful tool that allows the study of amendment decomposition under field conditions over relatively short time frames.

Introduction

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 (Parton and Rasmussen, 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, to help predict long-term SOC trends on organic farms and thereby 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 (Stöckle 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* [our italics] lower and upper boundaries of tillage effects on SOC oxidation rates” (Stöckle et al., 2010).

We would like 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.

In organic systems nutrients are often supplied via organic amendments The oxidation of these amendments confounds the measurement of the effects of tillage on *bone fide* SOC. This study will differentiate amendment from SOC oxidation by taking advantage of differences in the ratio of naturally occurring stable carbon isotopes ^{12}C and ^{13}C ($\delta^{13}C$) 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 the Pacific Northwest is primarily derived from C3 plants, its $\delta^{13}C$ is very different than that of corn or the manure of corn-fed animals. We can measure small differences in $\delta^{13}C$ using isotope ratio mass spectrometry. By introducing corn-based carbon into the soil, we hope to differentiate the decomposition of the amendment from the original SOC. The natural abundance of carbon isotopes has been used effectively to quantify the sources of changes in SOC within a relatively short time frame (Collins et al., 2010). Furthermore, $\delta^{13}C$ has been shown to be a more sensitive measure of SOC dynamics than total C (Lynch et al., 2006). For this technique to work a distinct $\delta^{13}C$ signature from the manure needs to remain in the soil after incorporation of the amendment to follow the fate of the manure C for multiple years.

Our goal was 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 in the calculation of the SOC decomposition rate. Our first objective was to determine whether the $\delta^{13}C$ signal from fresh dairy manure resided in the soil long enough to provide the data necessary to assess the parameters needed for CropSyst. Our second objective was to determine the decay constant, *k*, for fresh dairy manure.

Methods and Materials

To explore the technique of using stable isotopes to assess SOC decomposition, we measured the change of $\delta^{13}C$ in the soil of non-vegetated plots amended with fresh corn-based dairy manure. The study site was located at the Washington State University Puyallup Research &

Extension Center in western Washington state. The soil at this site is a Puyallup fine sandy loam. The plots were established on certified organic ground that had been in unimproved pasture for seven years. When we initiated the experiment, the vegetation on the plots was a mixture of various C3 species, but was dominated by *Poa pratensis*, a sod-forming grass. Plots were 1.52 x 4.57 meters, arranged in a randomized complete block experimental design with 4 blocks. Each block contained 2 plots, one of which received no manure (control) and the other of which received 59 kg of fresh dairy manure. The above-ground vegetation and sod were removed from the control plots with a sod cutter set at approximately 3 cm depth. On the plots that received manure, above ground biomass was collected from one representative 0.5 m^2 area in each of the four plots. This biomass was dried to constant mass at 45 ^{o}C to determine the amount of green manure present in the plot. For calculations of green manure biomass, we assumed a root:shoot ratio of 1.41 (Kelly, 1975) with 80% of the root biomass assumed to be concentrated in the top 15 cm of soil. The manure (urine and feces) was collected into 120 L plastic garbage cans from the Werkhoven Dairy in Monroe, WA. About 70% of these cows' diet was corn-based. The day after the manure was collected the plots were disked to break up the sod. The manure was then poured from the garbage cans over the plots and raked over the plots by hand to distribute it evenly. Finally the plots were worked to a depth of 15 cm with a spader. We assessed $\delta^{13}C$ at 6 times during the growing season. The experiment was begun in the spring of 2012 with pretillage sampling 15 May, incorporation of manure 18 May and subsequent sampling times 25 May, 11 July, 7 August and 9 September (days of year (DOY) 136, 139, 146, 193, 220 and 253, respectively).

Two of the plots receiving manure were instrumented to record soil moisture with water content reflectometers (Model CS615, Campbell Scientific, Inc., Logan, UT). Sensors were placed to measure the top 15 cm of soil. Soil moisture data were recorded hourly with a datalogger (Model CR10X, Campbell Scientific, Inc., Logan, UT) for the duration of the experiment. The plots were not irrigated. Plots were weeded as needed with a wheel hoe.

At each of the 6 sampling times, 6 soil cores from the top 15 cm of soil were removed from each plot. These 6 cores were composited, dried at 45^{o}C, sieved to pass 2 mm, ground, and then analyzed. A preliminary soil analysis was done by Soiltest Farm Consultants, Inc. (Moses Lake, WA) to determine soil organic matter. Soil organic matter was assumed to be 58% carbon. All $\delta^{13}C$ analyses were done by the Stable Isotope Core Laboratory at the Laboratory for Biotechnology and Bioanalysis, School of Biological Sciences at Washington State University. Sample carbon was converted to CO_2 with an elemental analyzer (ECS4010, Costech Analytical, Valencia, CA), separated with a 3 m GC column and analyzed with a continuous flow isotope ratio mass spectrometer (Delta Plus XP, Thermofinnigan, Bremen). In addition to the soil samples, $\delta^{13}C$ was measured for the dairy manure and cover crop tissue.

The changes in soil carbon from various sources was assessed as described by Collins et al (2010). The change in soil carbon from manure was assessed as

$$C\ from\ manure\ (\%) = \frac{\delta^{13}C_{amended\ soil} - \delta^{13}C_{green\ manure\ tissue}}{\delta^{13}C_{dairy\ manure} - \delta^{13}C_{green\ manure\ tissue}}. \qquad \text{[Eq. 1]}$$

Once the kpercentage of remaining manure-derived C percentage was known it was converted to mass and then used to calculate the rate of loss for each post-tillage sampling interval. The decay constant, *k*, was then estimated using a single pool model after Paul *et al*. (2001)

$$dC_S/dt = C_0 k e^{-kt} \quad \text{[Eq. 2]}$$

where C_S is the amount of remaining C at time *t*, C_0 is the amount of manure-derived C at time zero, *k* is the decomposition rate constant and *t* is time.

The decay constant, *k*, was estimated using PROC NLIN of SAS (SAS, 2008) with Equation 2 in the model statement. We used the Marquardt method option in PROC NLIN. Analysis of variance was conducted using the MIXED procedure of SAS with mean comparison by the diff option in the lsmeans statement of PROC MIXED (Littell *et al*., 2006).

Results

Soil organic matter prior to the addition of manure was 2.82%. $\delta^{13}C$ of the dairy manure and green manure were -20.93 ‰ and -30.01 ‰, respectively. SOC at the start of the experiment was 27,969 kg C ha^{-1}. We added 2808 kg C ha^{-1} from the green manure and 2722 kg C ha^{-1} from the manure.

Soil moisture remained relatively high for most of the growing season (Fig. 1). Periodic rainfall events occurred for more than half of the season, so soil moisture remained above 20% until about DOY 210 (Fig. 1).

Seasonal changes in $\delta^{13}C$ are presented in Figure 2. Upon tillage, both soils showed an increase in $\delta^{13}C$, but the increase was significant only in the manure-amended soil. From the time the manure was applied until DOY 193, the manure-amended soil consistently had a less negative $\delta^{13}C$ than did the control soil, although the difference was statistically significant only on DOY 139 which was immediately after incorporation of the manure. By the end of the growing season, even the trend had disappeared – there was little difference between the two treatments with respect to $\delta^{13}C$ (Fig. 2). By DOY 253 the $\delta^{13}C$ of neither soil differed significantly from its respective pre-tillage value on DOY 137 (Fig. 2).

The single pool C decay model (Eq. 2) provided a good fit to the raw data (Fig. 3). The predicted equation was

$$dC_s/dt = 2.21E7 * 0.0642 * e^{(-0.0642t)}.$$

The decay constant, 0.0642 d^{-1}, represents a turnover time of 15.6 days and a half-life for dairy manure C of about 11 days. Given these parameters, the calculated quantity of manure C lost from DOY 139, when the manure was applied, to the end of the experiment on DOY 253,

$$\int_{139}^{253} [C_o k e^{(-kt)}] dt,$$

was 2940 kg C ha^{-1}.

Discussion

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 difference between the $\delta^{13}C$ of the manure and the $\delta^{13}C$ of the parent soil was not high enough for a significant trend to be visible. Furthermore, the decay of the manure was too rapid for the $\delta^{13}C$ from the amendment to be retained for the period of time necessary to meet our first objective. Finally, the relatively high soil organic matter (2.8%) in our study soil overwhelmed the $\delta^{13}C$ signature of the added carbon in the manure. About 8% of the total C in the top 15 cm of soil was added via manure. This technique might be feasible in low-SOM soil that had been cropped with C4 species for many years, but these conditions are relatively rare in the Pacific Northwest (see Collins et al, 2010 for an exception).

Soil moisture remained high enough to sustain microbial activity for most of the growing season (Fig. 1). Adequate soil moisture, particularly early in the season, led to a fairly rapid decomposition of the applied manure (Fig. 3). The calculated dairy manure carbon loss of 2940 kg C ha^{-1} was somewhat higher than the quantity of carbon we applied, 2722 kg C ha^{-1}. Given the multiple sampling and analysis errors involved in arriving at both of these numbers, we were pleased that they corresponded as well as they did. The decomposition rate constant, $k = 0.0642$ d^{-1}, was comparable to other studies. Decomposition constants for cattle manure incubated in sand reported by Murwira et al. (1990) ranged from a low of 0.025 d^{-1} to 0.072 d^{-1}. In another study, decomposition rate constants for cow manure in 3 different soils were 0.0685 d^{-1}, 0.0683 d^{-1} and 0.0688 d^{-1} (Ajwa and Tabatabai, 1994). Cattle farmyard manure incubated 21 d in soil in the laboratory had $k = 0.011$ d^{-1} (Saviozzi et al., 1993).

In a similar study using pig slurry from corn-fed pigs, the pig slurry $\delta^{13}C$, -20.0 ‰, was very similar to what we found in our dairy manure (Angers et al., 2007). These authors found that 20% of the pig slurry carbon was lost in the first 22 days after incorporation of the slurry into the soil. In our study, approximately 75% of the manure carbon had been lost at 21 days. One possible explanation for the difference between the two studies (beside the use of different materials) is that Angers et al (2007) used pig slurry that had been stored anaerobically for 6 months and they buried the slurry under 10 cm of soil whereas we used fresh manure and incorporated it relatively evenly within the tillage layer.

Several studies have reported decomposition constants for common farm manures and for municipal wastes. Sewage sludge and municipal solid wastes had *k*-values averaging 0.0675 d^{-1} (Pascual et al., 1998), or, for sewage sludge, 0.088 d^{-1} (Saviozzi et al., 1993). Pig slurry had *k* of 0.076 d^{-1} (Saviozzi et al., 1997) or 0.2 d^{-1} (Saviozzi et al., 1993). Poultry tended to have higher *k*-values, ranging from 0.159 d^{-1} (Saviozzi et al., 1993) to an average of 0.40 d^{-1} (Martín et al., 2012).

Most of the cited *k* determinations assessed the decay constants of amendments using laboratory incubations in soil, and more examples exist (e.g., Sleutel et al., 2005). But relatively few studies have used the $\delta^{13}C$ signature of C4 species to characterize the decay of particular amendments within a mixture of sources under field conditions. Rochette et al. (1999b) used carbon isotopes to separate soil respiration into soil and plant components and to assess the decomposition of maize residue in soil (Rochette et al., 1999a). These latter studies and the work we report here indicate that the use of the native abundance of carbon isotopes is a powerful tool that can be used effectively to tease out important aspects of soil carbon dynamics from complex mixtures of carbon pools, even in the short term.

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Figure 1. Seasonal trend in volumetric water content of soil amended with fresh dairy manure on day of year 139 at the Washington State University Research and Extension Center, Puyallup, WA in 2012. Each line provides data from one plot.

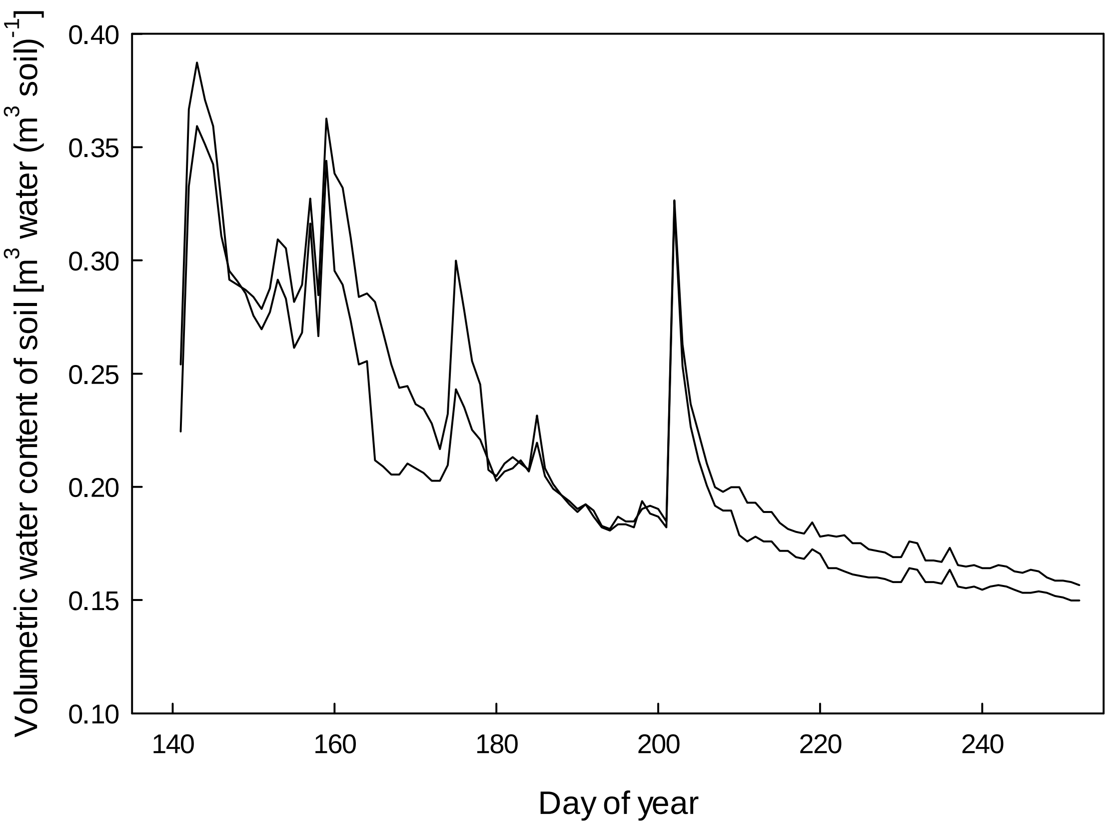


Figure 2. $\delta^{13}C$ of soil sampled on six dates in 2012 at the WSU Puyallup Research and Extension Station. Soil was either left untreated or was amended with fresh, corn-based, dairy manure on day 139. Within a date, there were no significant differences between the treatments except on day 139 when the $\delta^{13}C$ of the manure-amended soil was significantly higher than the control soil.

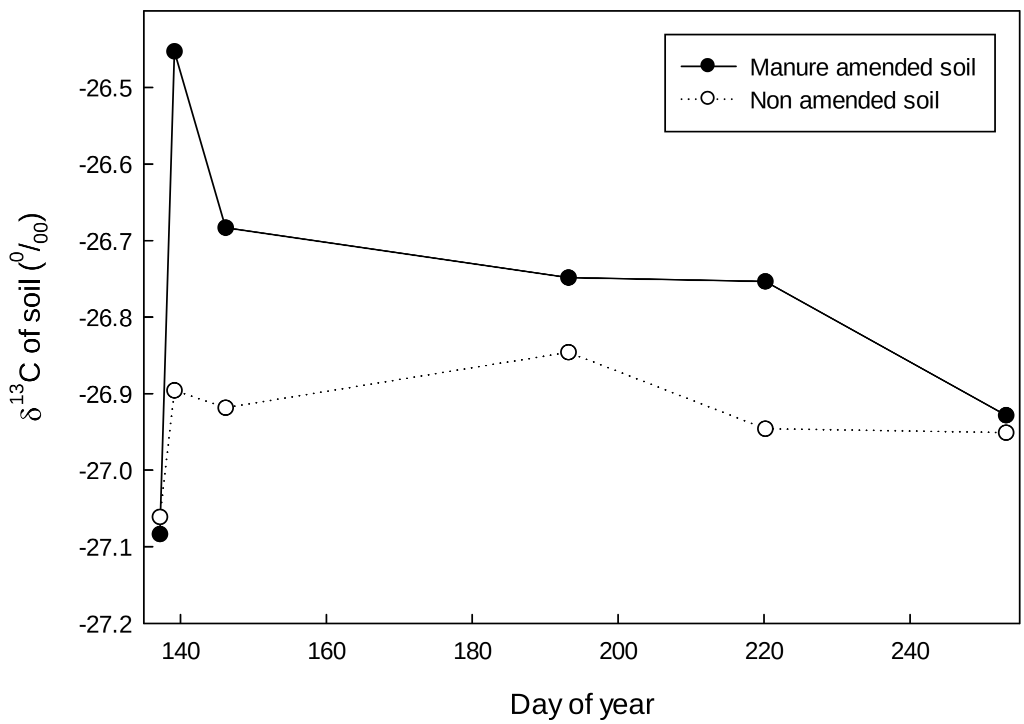
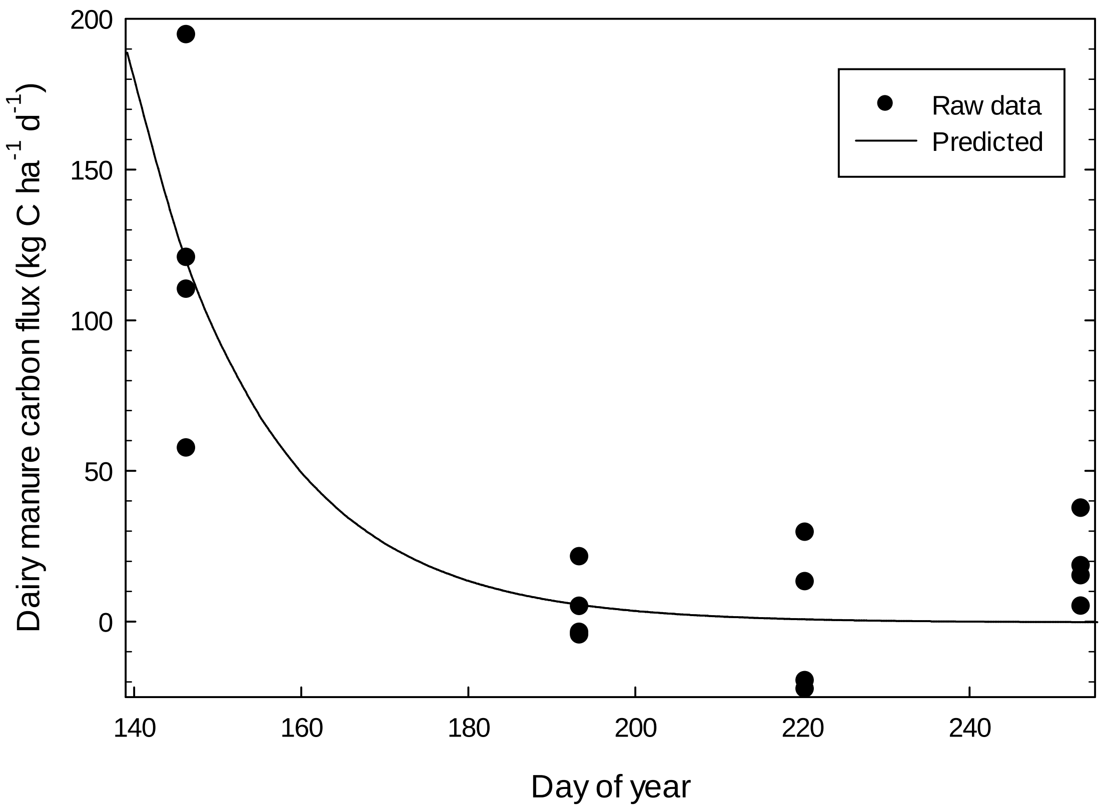


Figure 3. Seasonal loss of fresh dairy manure carbon during the 2012 growing season at the WSU Puyallup Research and Extension Station. Soil was amended on day 139 with fresh dairy manure. Decay constant, *k*, for fitted line was 0.064 d^{-1}.



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