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Annual dynamics of soil organic matter in the context of long-term trends

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[1] Long-term research has provided a great deal of information regarding the influence of management on the equilibrium dynamics of soil organic matter (SOM), although short-term dynamics remain largely uninvestigated. An improved approach to characterizing SOM dynamics in managed ecosystems would consider both short-term and long-term changes in content and composition. This approach and its implications are illustrated for an experimental site comparing agricultural management practices. Changes in soil C composition were assessed semiquantitatively using ^{13}C natural abundance measurements, demonstrating their useful although rarely applied role in short-term studies. This information is a valuable complement to long-term data, since net differences since the site's inception fail to reveal a timeline marked by repeated changes in soil C content and composition. Such data are also useful for reinforcing and understanding long-term simulation models, which are typically driven by temporally dynamic events but are often fit against temporally sparse SOM data sets. *INDEX TERMS:* 1615 Global Change: Biogeochemical processes (4805); 1645 Global Change: Solid Earth; 1694 Global Change: Instruments and techniques; *KEYWORDS:* ^{13}C natural abundance, agroecosystems, long-term, management, short-term, soil carbon

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1. Introduction

[2] Soil organic matter (SOM) is a fundamental on-site resource for sustained use of agricultural land [*Allison*, 1973; *Schnitzer and Khan*, 1978; *Doran and Parkin*, 1994; *Tiessen et al.*, 1994; *Paul et al.*, 1997a]. Management affects SOM by manipulating inputs, residue composition and decomposition, soil physical properties, nutrient availability, and soil fauna [*Fernandes et al.*, 1997; *Paustian et al.*, 1997]. Characterizing SOM, including its chemical and physical properties, supply and storage of nutrients, and changes over time, is an important part of understanding any ecosystem.

[3] The long-term behavior of SOM has been documented in a variety of settings, many times in experimental sites designed to observe the effect of management on crop yield. These sites have yielded valuable information concerning the changes induced by different practices, studied from agronomic to environmental and even economic points of view [*Leigh and Johnston*, 1994; *Rasmussen et al.*, 1998]. Short-term measurements of SOM, however, are regarded differently, as researchers are often in doubt not as to the value of reliable data, but as to the possibility of obtaining it. It is generally considered [e.g., *Gregorich et al.*, 1994; *Paustian et al.*, 1995, 1997; *Bolinder et al.*, 1998; *Körschens et al.*, 1998; *Rasmussen et al.*, 1998] that a brief (seasonal or annual) approach to observing management-induced changes in SOM as a whole will most likely be unfruitful. This point of view is based mainly on the fact that the total amount of C in soils is usually large compared to the amount cycled on a short-term basis. More commonly, certain components of SOM, such as mineralizable C, the light fraction, microbial biomass, or other chemically or physically extractable fractions, are isolated, since these often respond quickly to and more sensitively manifest seasonal changes in soil conditions.

[4] Agricultural land, by nature, is in a continual state of change; it follows that short periods, in dynamic systems, might provide the opportunity to observe changes in whole soil C. Instances of seasonal and annual variation or trends in SOM content are apparent in many works, including those of *Angers* [1992]; *Leinweber et al.* [1994]; *Crocker and Holford* [1996]; *Klír* [1996]; *Hendrix* [1997]; *Lyon et al.* [1997]; *Mahmood et al.* [1997]; *Kieft et al.* [1998]; and *McCarty et al.* [1998]. The effects of short-term changes in inputs and site conditions on SOM, while acknowledged, are not well researched, although understanding such changes can be useful in characterizing different systems as well as comparing systems that vary in the quantity and quality of inputs.

[5] To complement information about changes in soil C content, natural abundance ^{13}C measurements are a convenient way to observe overall changes in soil C composition. This technique, in which differences in isotopic composition between C_3 and C_4 plants serve as a tracer of C produced in

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situ, has formed the basis for many long-term studies centered around vegetation changes; as explained by *Bernoux et al.* [1998] and *Boutton et al.* [1998], the change in isotopic composition of SOM caused by the input in question exists for an amount of time determined by the rate of replacement (turnover) of soil C. Use of natural abundance ^{13}C measurements is regarded as a versatile and practical way to study soil C dynamics as affected by changes in vegetation or crop rotation patterns over extended periods [e.g., *Cerri et al.*, 1985; *Balesdent et al.*, 1987; *Schimel et al.*, 1994; *Balesdent and Mariotti*, 1996]. This tool has rarely been applied to short periods in whole soils, presumably because of the reasons mentioned above for total soil C, although it would allow a more in-depth description of the fate of recently added C if and when significant changes are observed.

[6] An improved approach to characterizing SOM dynamics in many instances would integrate both short-term and long-term changes in soil C content and soil C composition, such as reflected in isotopic data. It was our objective to (1) demonstrate this approach at an experimental site comparing conventional and alternative agricultural management, using annual changes in soil C content and composition to describe nonequilibrium dynamics (i.e., the immediate effects of inputs, management decisions, and site conditions), and (2) to show the impact of different management practices on soil carbon storage and dynamics at this site, using annual data to complement steady state data and long-term trends.

2. Methods

2.1. Site and Management

[7] All data were taken from the Sustainable Agriculture Farming Systems (SAFS) long-term project, established in 1988 at the University of California at Davis to compare agricultural systems representative of California's semiarid, irrigated Sacramento Valley [*Temple et al.*, 1994]. The soil at the SAFS site (38°32′N, 121°47′W, 18 m elevation) is classified in part as Reiff loam (coarse-loamy, mixed, nonacid, thermic Mollic Xerofluvents) and in part as Yolo silt loam (fine-silty, mixed, nonacid, thermic Mollic Xerofluvents); it is a mollic fluvisol under FAO classification. Soil pH ranges from 6.9 to 7.2. Carbonates are negligible in SAFS soil. Annual rainfall typically ranges from 400 to 500 mm, occurring mostly in winter, and daytime temperature during the summer season averages between 30° and 35°C. Prior to establishment of the SAFS project, the site consisted of conventionally managed wheat, bean, and alfalfa (*Medicago sativa* L.).

[8] The SAFS project includes four management systems that differ in crop rotation and use of inputs (Table 1). These are replicated in each of four randomized blocks. Within each block, each farming system area is further split into one plot (0.12 ha) for each possible crop rotation entry point, for a total of 56 plots at the site. All possible crops are therefore present each year in each system.

[9] Almost all of the synthetic fertilizer nitrogen application in the conventional and low-input tomato and corn crops occurs several weeks after planting. Compost or partially composted poultry manure in the organic plots, typically between 2 to 6 Mg C/ha, is applied to tomato and corn crops shortly before planting. Safflower and bean crops are fertilized only in the conventional plots (the low-input and organic crops receive cover crop N). In the organic and low-input systems, the cover crop preceding tomato and corn is vetch (*Vicia spp.*), an aboveground input typically between 1 and 2 Mg C/ha at the time of incorporation. Cumulative input of C over time has followed the order organic > low-input > conv-4 > conv-2. Overall external inputs of N have been comparable between the organic and conv-4 systems, while significantly less has been applied to the conv-2 system and even less in the low-input plots. Tillage occurs around the same time in each system, primarily the incorporation of cover crops, manure, or crop residues. This can disturb the soil up to, but usually less than, a depth of about 30 cm.

[10] At SAFS, the C_4 plants corn (*Zea mays* L.) and sudangrass (*Sorghum bicolor*) serve as sources of ^{13}C enrichment, allowing semiquantitative assessment of the incorporation of C derived from these and other crops into soil C. Sudangrass is not a main (summer) crop, but a cover crop typically grown in the months following a tomato crop. Typical δ^{13}C values of corn and sudangrass are −12 to −13‰, other summer crops and C_3 cover crops −26 to −28‰, and composted manure about −20 to −21‰.

2.2. Soil Samples

[11] Soil samples were taken up to a depth of 30 cm so as to account for the potential influence of tillage, and split into a 0–15 cm and a 15–30 cm sample. Each sample is a composite of 20–30 cores (2.5 cm diameter each) taken throughout a given SAFS plot. Following collection, samples were homogenized by sieving (4 mm) and then air-dried. To prepare the samples for analysis, free debris was removed as in other studies [e.g., *Dzurec et al.*, 1985; *Paul et al.*, 1997b; *Boutton et al.*, 1998]: four to five grams of soil were suspended in 10 mL aqueous NaCl (density ~1.2 g/mL). The samples were thoroughly dispersed, centrifuged, and the solution poured off along with any debris that floated. (A test of solutions of greater density did not result in removal of any more free organic matter from this soil than did a solution of density 1.2 g/mL.) This was repeated with water, after which the samples were dried and ground in ball milling cylinders. In this way, soluble C and all plant remains and partially decomposed material, including fine roots, were removed, leaving only the organomineral component of SOM, the bulk of soil C, material which has been altered or "humified" and held to the soil matrix. All further mention of SOM or soil C refers to this interpretation.

[12] For the purposes of the present study, it was desirable to recognize changes only if they had occurred in the organomineral SOM, or if C inputs had been transformed sufficiently so as to become part of this component. Free organic matter, such as partially decomposed manure, plant residue, or fine roots, can often vary substantially on a seasonal basis; even a small amount can influence soil C measurements. This is especially important to consider when including ^{13}C measurements, in which case small residual pieces of C_4 plants, for example, may contribute significantly to overall soil δ^{13}C values.

Table 1. Management Systems at the Sustainable Agriculture Farming Systems (SAFS) Site

System	Crop[a] Rotation	Description
Organic	tomato safflower corn oats/vetch/pea[b]; bean	Four-year, five-crop rotation using poultry manure (composted or partially composted) and legume and grass cover crops; no synthetic pesticides or fertilizers are used.
Low-input	tomato safflower corn oats/vetch/pea; bean	Four-year, five-crop rotation in which inputs consist of cover crops plus fertilizer applied at one third to one half of the conventional rate; pesticide/herbicide use is minimal.
Conv-4	tomato safflower corn wheat[b]; bean	Four-year, five-crop rotation using synthetic fertilizer and pesticides/herbicides at conventionally recommended rates.
Conv-2	tomato wheat	Two-year, two-crop rotation using synthetic fertilizer and pesticides/herbicides at conventional rates.

[a] Tomato, *Lycopersicon esculentum* Mill.; safflower, *Carthamus tintorius* L.; corn, *Zea mays* L.; oats, *Avena sativa* L.; vetch, *Vicia spp.*; pea, *Pisum sativum* var. arvense; bean, *Phaseolus vulgaris* L.; wheat, *Triticum aestivum* L.

[b] Pea included beginning in 1997. Oats/vetch/pea and wheat are winter crops.

[13] Analysis of total C and isotopic composition was by continuous flow combustion IRMS (20-20/ANCA-NT, Europa, UK). All samples were analyzed twice for increased precision. Overall precision (standard deviation) of a working soil standard, reflecting sample preparation as well as analytical variability, was 0.2 mg/g for soil C and 0.07‰ for δ^{13}C. Carbon-13 values are expressed relative to the Peedee belemnite reference.

[14] In Figures 1 to 4, means across time in the same system were analyzed using repeated measures ANOVA-Student Newman Keuls (SNK) test, and means across systems at the same date using ANOVA-SNK; differences are marked as significant when $P \leq 0.05$. A line is drawn through points only as an aid in visualizing trends; points spanning more than one season should not be assumed to be "connectable."

3. Results

[15] To compare long-term accumulation of SOM in the SAFS management systems, Table 2 shows soil C content after 8 and 12 years, corresponding to two and three complete 4-year rotations. Twelve-year soil C values are also expressed relative to an initial value in 1988, estimated on the basis of initial values of SOM, which were the same in all yet unestablished treatments [*Scow et al.*, 1994]. Data are given from each entry point (the average of four plots), as well as an overall average for all the plots in each system (eight in conv-2, 16 in the other systems). Soil bulk density at SAFS is not different among systems; the mass of soil C on an area basis shows the same differences outlined in Table 2.

[16] At SAFS, the presence of corn in the rotation is likely responsible for part of the increase in soil C observed over time. Inclusion of this crop, which is the main difference between the conv-4 and conv-2 management, likely produced most of the additional soil C by which the conv-4 system surpasses the conv-2 system. Low-input management has increased soil C even more with the inclusion of winter cover crops, and in the organic system a further increase was observed with the inclusion of manure. Soil C accumulation appears to be stabilizing somewhat, in that there was little additional change from 1996 to 2000.

[17] Figures 1 to 4 depict progressions of surface soil C content and isotopic composition using those sets of plots for which the most complete timelines could be constructed on the basis of available data; each figure follows a different set of four plots in each system. The standard error of each measurement (representing four plots) is shown to give an idea of the variability among plots. It is generally recognized that in many cases, inherent heterogeneity among plots can be high, depending on the condition and history of a site. The degree of variability among plots might easily be greater than temporal variability (dynamics) within a treatment or differences between treatments, although the test of significance will ultimately resolve whether or not these are true differences or are instead overshadowed by the variability among plots.

[18] Although potentially part of the plow layer, rarely was any significant temporal variability seen in the 15–30 cm depth (data are not shown), and when seen, it was slight compared to the degree of change in the corresponding 0–15 cm sample. Nor was any behavior observed that might counter the data from the surface 15 cm, i.e., some opposite dynamic in the 15–30 cm layer that might "cancel out" that observed in the 0–15 cm layer. The data presented here focus only on the more dynamic surface soil.

[19] The intent of Figures 1–4 is to consider annual changes as part of a trend encompassing many seasons. While the overall progress of the SAFS systems can be seen over time, it is also clear that soil C as well as input-derived C, reflected in isotopic composition, have varied continuously during the years shown. Even as the amount of soil C accumulated at SAFS appears to be stabilizing (changing little from 1996 to 2000; see Table 2), annual variability persists.

[20] Some observations on how SOM dynamics differ among the SAFS systems can be made with this data set. For example, from the beginning to the end of the 1993–1997 rotation shown in Figure 1, a significant increase in soil C occurred in the organic and low-input plots. In

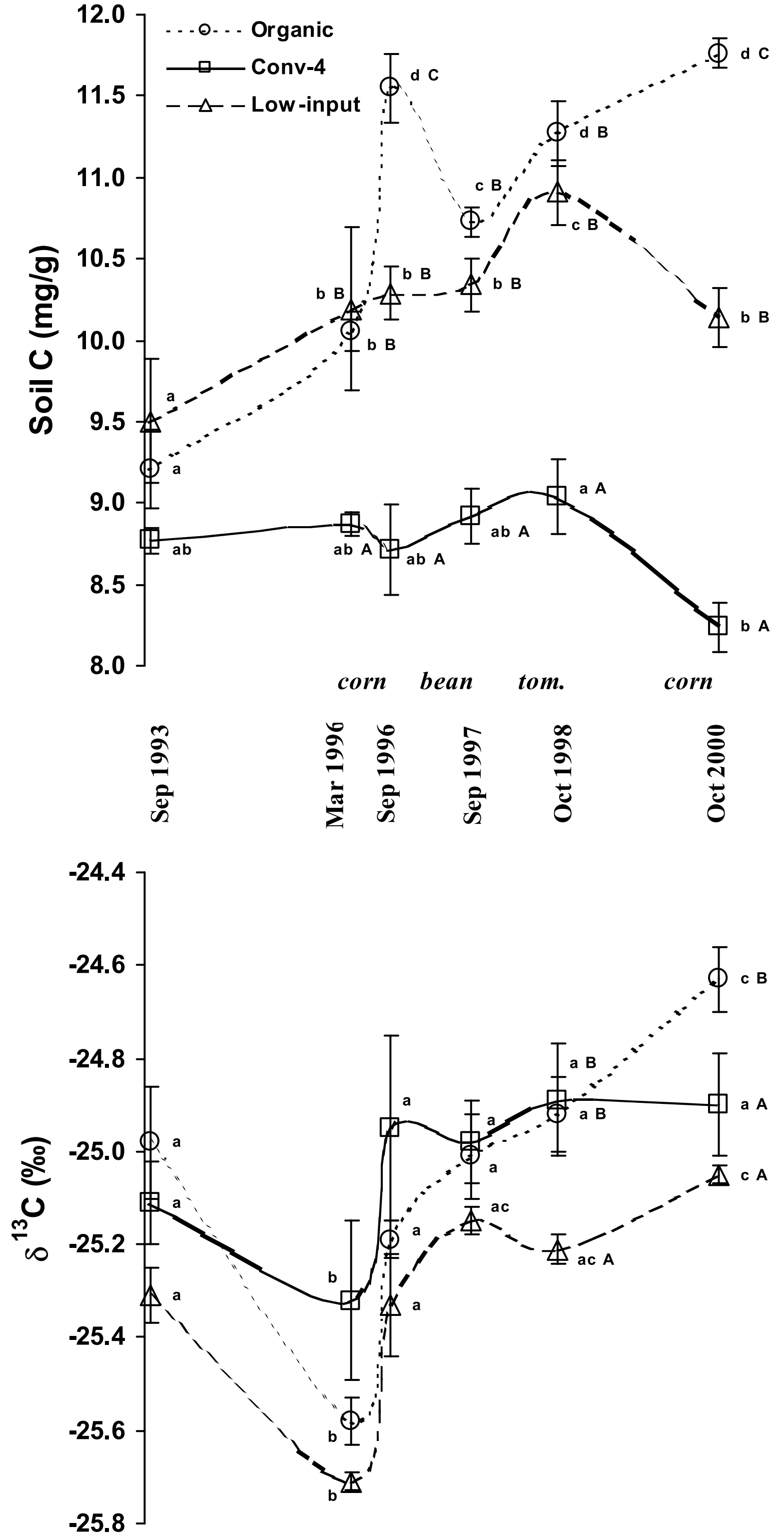

Figure 1. Changes in soil carbon content and isotopic composition in four different management systems (described in Table 1), using those series of replicated plots for which the most complete timelines could be constructed. Vertical bars show standard errors of means. Significant differences between dates in the same system are indicated with different lowercase letters. Significant differences between systems at a given date are indicated with different uppercase letters.

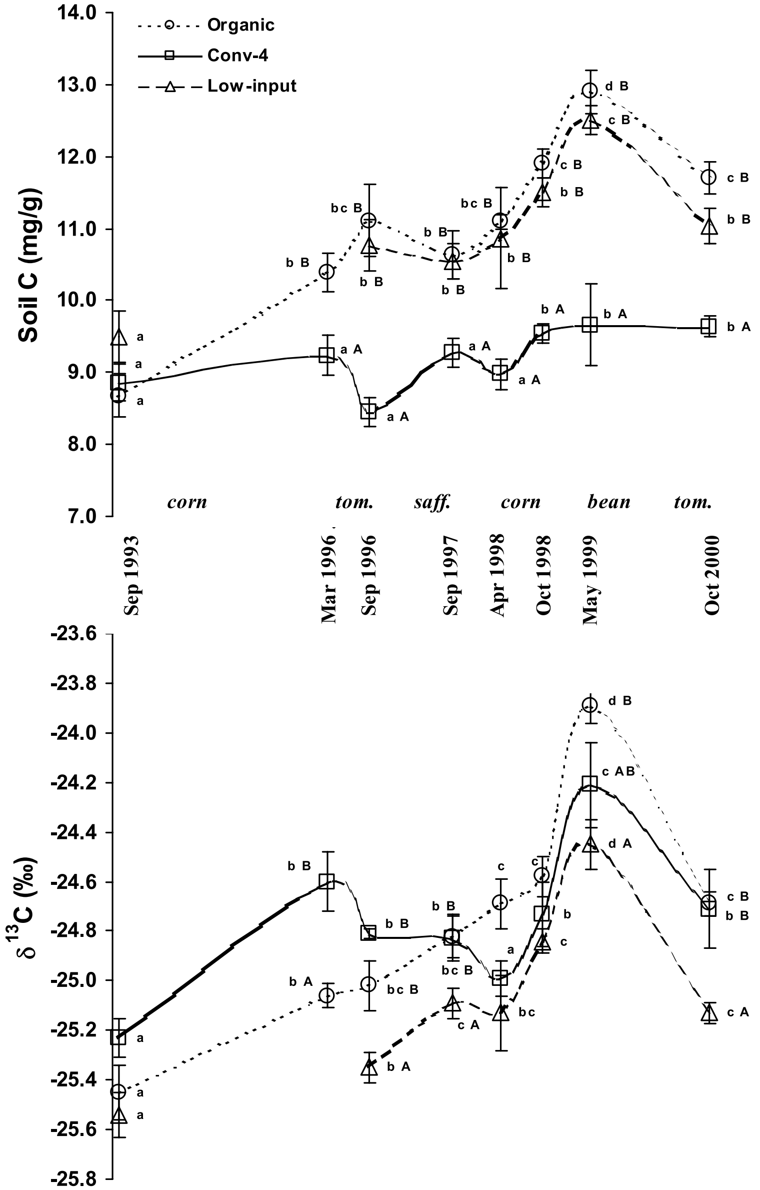

Figure 2. As in Figure 1, but for a different set of plots.

addition, the organic system showed the greatest variation in soil C content between the initial and final points of both rotations contained in Figure 1 (1993–1997 and 1996–2000). From September 1993 to March 1996, $\delta^{13}C$ decreased significantly in all three systems; the soil subsequently became enriched in ^{13}C during the 1996 corn season. The addition of corn-derived C to SOM during this season was therefore comparable to the cumulative addition of C to SOM from all other (non-C_4) inputs during the previous three years.

[21] The same dates describe different rotations in Figure 2. The conv-4 system showed the most fluctuation in ^{13}C content. These plots remained relatively constant in soil C content except for an increase during the 1998 corn season and a decrease during the 1996 tomato season (the latter significant at $P = 0.075$). Significant net increases in soil C occurred in the organic and low-input plots between the beginning and end of the 1993–1997 rotation, and in the conv-4 plots during the 1996–2000 rotation.

[22] In general, the organic and low-input systems closely paralleled each other in accumulation of C and ^{13}C, although the low-input system showed more changes in crop-derived C than the organic system. Interestingly, the low-input plots almost always display the lowest soil $\delta^{13}C$ values throughout Figures 1 to 4, oftentimes significantly. The amount of C_4-derived C in this system is therefore consistently less than in the other two systems. The conv-4 system, on the other hand, experienced the least amount of accumulation of soil C but the greatest turnover of soil C, as evidenced by the higher amount of fluctuation in soil $\delta^{13}C$ coupled with a relatively noneventful soil C timeline. In other words, the accumulation of new crop-derived soil C

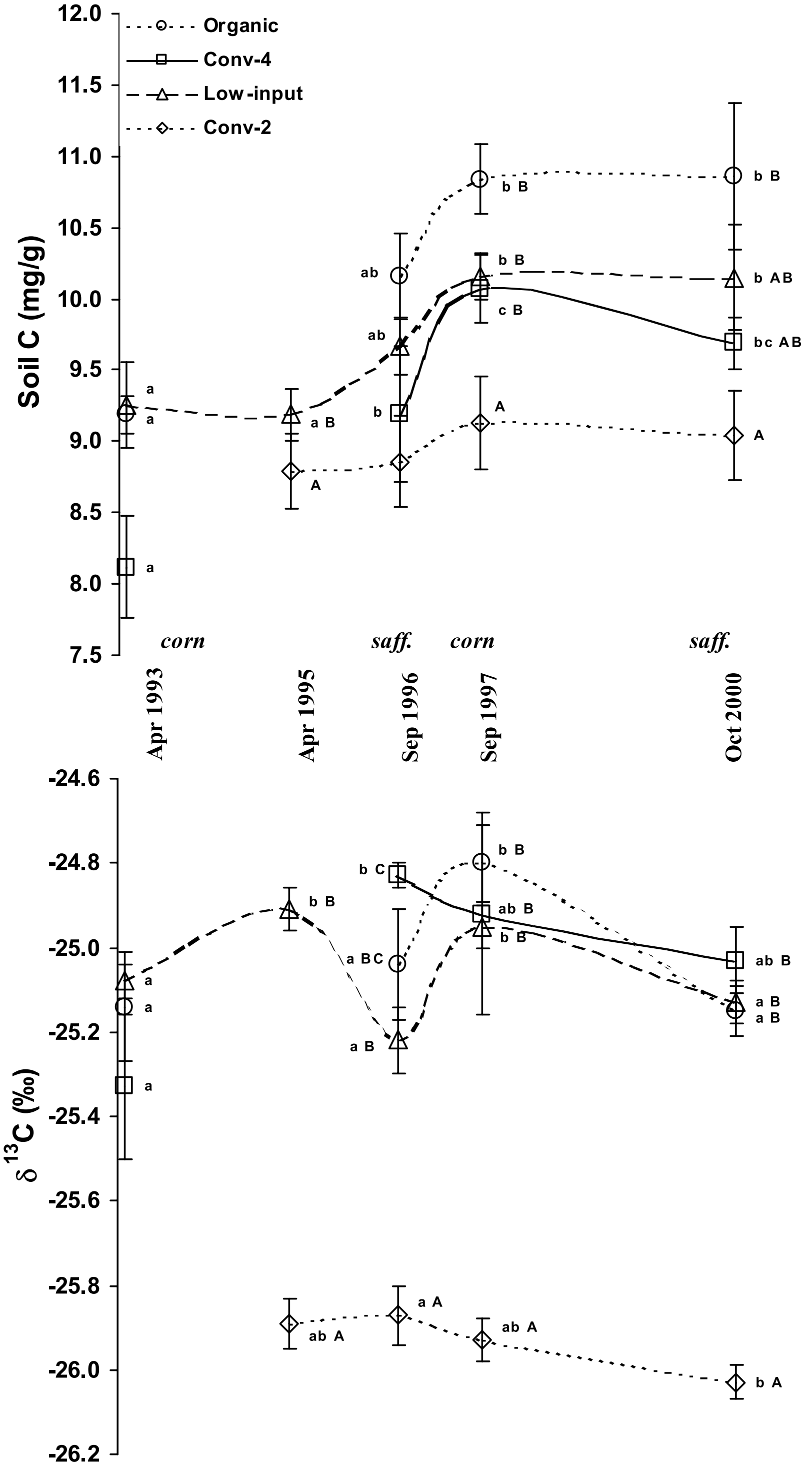

Figure 3. As in Figure 1, but for a different set of plots.

did not seem as permanent in the conventional systems as in the cover crop-based systems.

4. Discussion

4.1. Measurement of Soil $\delta^{13}C$ Over Short Periods

[23] Short-term study of SOM dynamics with the well-known ^{13}C natural abundance approach is scarce; such analysis of whole soil has mostly focused on SOM content alone. Natural abundance ^{13}C measurements taken in an attempt to observe changes during short periods have been put to only limited use, often in studies of mineralized C (carbon dioxide) [e.g., *Mary et al.*, 1992; *Cheng*, 1996; *Liang et al.*, 1999; *Bol et al.*, 2000], and seldom under field conditions [e.g., *Rochette and Flanagan*, 1997; *Rochette et al.*, 1999; *Glaser et al.*, 2001]. Two short-term studies [*Qian*

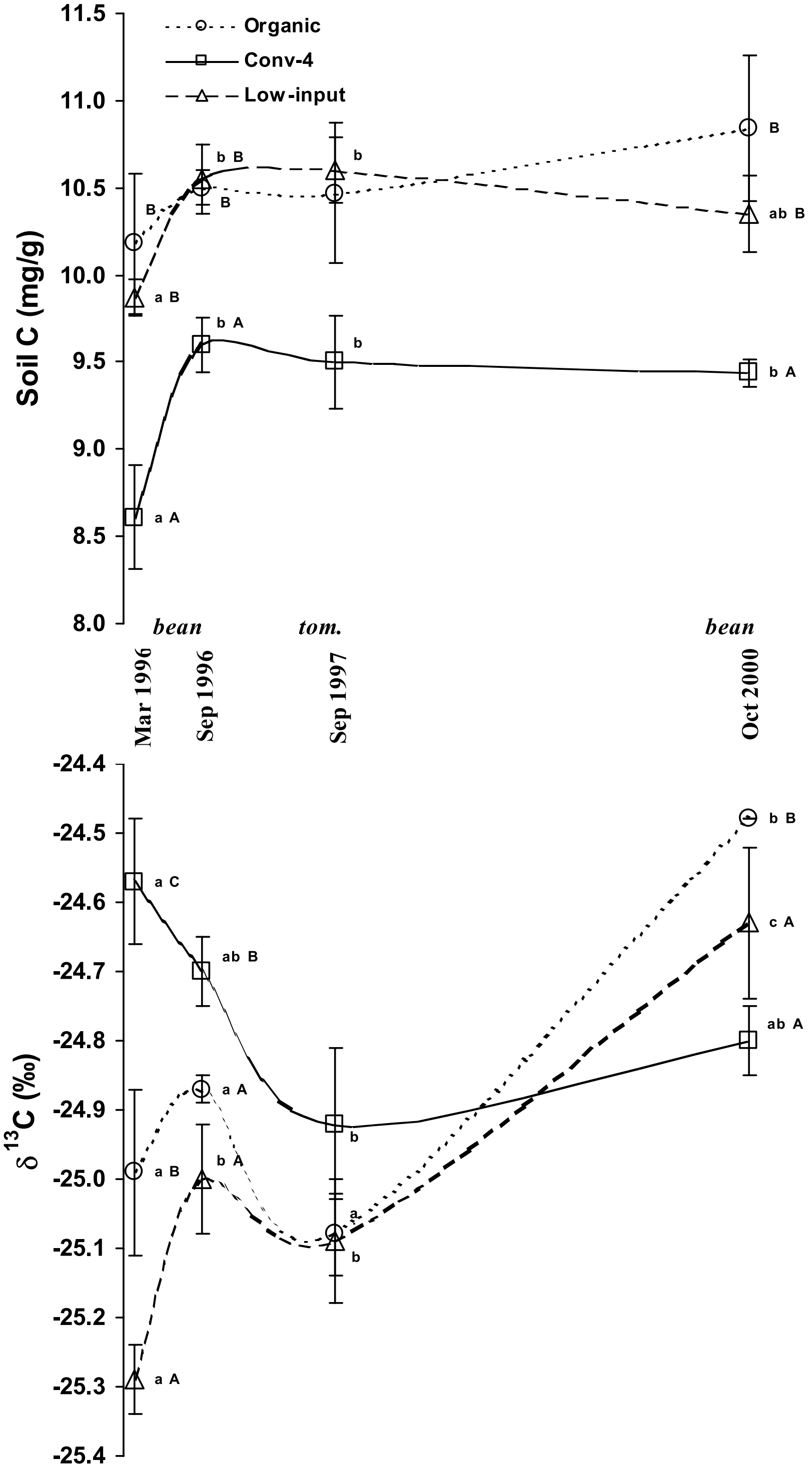

Figure 4. As in Figure 1, but for a different set of plots.

et al., 1997; *Liang et al.*, 2002] used whole soil analysis to determine C derived from growing roots. In our study, significant annual changes were evident in the soil as a whole even if much of this C is unresponsive (i.e., not actively cycling) on a short-term scale.

[24] The supposed high limit of resolution and often small annual increments of this natural tracer have led to the belief [e.g., *Balesdent and Balabane*, 1992] that this technique is best applied to whole soil after a number of successive cultivations of the crop used as the source of tracer, and even then only if this crop or its vegetation type (C_3 or C_4) has not been present on the site prior to initiating the study [*Balesdent et al.*, 1987, 1988]. In light of occasional studies such as those mentioned above, as well as the example of

Table 2. Soil Organic Carbon Content at SAFS After Two and Three Complete Rotations

System	Entry Point[a]	Soil C 1996,[b] mg/g	Soil C 2000,[b] mg/g	Percent Increase 1988–2000[c]
Organic	corn	11.6 c	11.8 c	41.7 c
	bean	10.5 b	10.8 b	30.6 b
	tomato	11.1 b	11.7 b	41.0 c
	safflower	10.2 a	10.8 a	30.6 a
	all plots	10.8 c	11.3 c	36.0 c
Low-input	corn	10.3 b	10.1 b	22.1 b
	bean	10.6 b	10.4 b	24.7 b
	tomato	10.8 b	11.0 b	33.0 c
	safflower	9.7 a	10.2 a	22.3 a
	all plots	10.3 b	10.4 b	25.5 b
Conv-4	corn	8.7 a	8.2 a	−0.7 a
	bean	9.6 a	9.4 a	13.7 a
	tomato	8.4 a	9.6 b	16.1 b
	safflower	9.2 a	9.7 a	16.7 a
	all plots	9.0 a	9.2 a	11.5 a
Conv-2	tomato	8.0 a	8.6 a	4.0 a
	wheat	8.9 –	9.0 –	8.9 –
	all plots	8.4 a	8.8 a	6.5 a

[a] Samples (at 0–15 cm depth) were taken following this crop in the fall of 1996 or 2000. "All plots" is an overall average of all the plots in a system.

[b] In each column, different letters at the end of each value indicate a significant difference (ANOVA-SNK, $P \leq 0.05$) between systems for the same entry point (or "all plots").

[c] Values were calculated using initial soil C in 1988 (8.3 mg/g, estimated from organic matter content which was the same in all yet unestablished plots).

the present study and the potential for obtaining useful results, more attempts to apply this approach are encouraged.

4.2. Using Short-Term Data to Support Long-Term Predictions

[25] The amount of C present in soil at any time reflects the relative magnitude of conversion of inputs into SOM versus loss of existing SOM. Many studies [see *Paustian et al.*, 1997], in addition to documenting the long-term effects of different management on SOM content, have also estimated the amount of C input necessary to maintain soil C levels. As discussed by *Paustian et al.* [1997], inputs are controlled in agriculture through crop selection, residue management, and use of external additions like manure. When seasonal soil measurements are taken, the immediate influence (or lack of influence) of different inputs, including the current crop, can be observed. In this way short intervals can be considered according to their effect on soil C dynamics under different management strategies and site conditions. Tentative hypotheses about long-term tendencies may then be supported using this information.

[26] Observations made during a short period represent the effect of a combination of conditions present during that time, the same conditions that ultimately govern long-term trends. Many, if not the large majority, of simulatory long-term SOM models [e.g., *Van Veen and Paul*, 1981; *Parton et al.*, 1987, 1988; *Li et al.*, 1994; *Ågren and Bosatta*, 1996; *Andrén and Kätterer*, 1997; *Grant*, 1997; *Smith et al.*, 1997, and references therein; *Molina et al.*, 2001] are inherently dependent on short-term information: monthly or yearly climatic, microbial biomass, plant production, residue decomposition, and other parameters form the basis for projecting the effects of management over much longer periods of time. Ironically, though, seasonally concentrated measurements of SOM content, the primary output of such models, are sparse, and these models must often be fitted to occasional data spread out over many years [see *Kelly et al.*, 1997, and references therein; *Smith et al.*, 1997; *Molina et al.*, 2001]. *Smith et al.* [1997] acknowledge that even within models designed to simulate changes in SOM over many decades, short-term data can be valuable for evaluating these models in their description of seasonal processes, the same processes that cumulatively (over time) determine long-term effects. *Hyvönen et al.* [1998] state that "predictions of future soil organic matter stores are. . .based mainly on extrapolations from observations of a short-term nature." In the opinion of *Van Veen et al.* [1984], "the ability of a simulation model to describe accurately not only short-term events. . .but also the same processes over, say a decade, is an important criterion in assessing its predictive power."

[27] As the long-term models recognize, management decisions, while most evident, may not always be the most important factors causing changes in SOM. Unpredictable variables such as crop yield and climate, almost always presented alongside SOM data in long-term contexts, can vary notably from year to year and can therefore have an important influence on short periods. Some changes observed in the present study, for example, did not recur in subsequent years, even under similar crop and input regimes. With this in mind, it may be suggested that comparisons between agroecosystems do not necessarily become "long-term" after a predetermined number of years have passed, but rather, once changes due to management (predictable conditions) begin to overshadow the variability

imposed by unpredictable conditions. In Figures 1–4 (although the complete history of the site is not documented), "long-term" cumulative changes can begin to be distinguished between the systems at SAFS after a decade or less of management.

4.3. Implications of Short-Term Changes

[28] Because of the dynamic nature of SOM accumulation and loss in dynamic ecosystems, a long-term trend may in fact be made up of a series of short-term variations potentially comparable in magnitude to long-term behavior. This can have considerable implications, as it does for the SAFS site, since long-term trends are usually presented as describing SOM at equilibrium, in the absence of confounding dynamic trends. Long-term measurements should not be presented without knowledge of possible short-term variability; such a valuable number as the change in soil C over many years may be influenced by the very month in which the initial or final measurements are taken. For example, the increase in soil C in the organic plots during the first corn season in Figure 1 is equal to the overall increase in soil C during the entire 1993–1997 rotation. In Figure 2, the decrease in soil C during the 1996 tomato season in the conventional plots is comparable to the net increase over the entire 7-year period shown in Figure 2. A long-term change documented from some faraway initial sample up to a sample taken before one of these dynamic seasons would be much different from the "same" change documented using a final sample taken after this season, although the long-term interval would be essentially the same (plus or minus several months).

[29] A comprehensive study of long-term trends would also, in theory, consider the entire depth of soil subject to changes in SOM. True measurements of "total" soil C pools, however, are rarely obtained; portions of the larger soil profile (e.g., the surface) are often taken and used to observe changes and differences in systems, somewhat analogous to the isolation of certain components (such as extractable C) from a larger sample of soil C. In this study only the surface soil was studied, it being the most dynamic, although deeper soil is also influenced by changes in inputs and other conditions. "Total" SOM levels may indeed change slowly, but SOM in surface soils does not always behave similarly.

[30] *Leinweber et al.* [1994] appropriately emphasize the "fundamental importance of poorly understood seasonal changes for SOM dynamics in agroecosystems." *Balesdent et al.* [1988], in a long-term analysis of soils from a long-term site, discuss the significance of annual replacement of SOM. *Gregorich et al.* [1994], in discussing indicators of soil quality, including soil organic C, remark that "more work is required...to determine the variability of each property in the data set. Each property may need to be characterized for its temporal variation during a growing season..." Together with such work, the example of the present study highlights the importance of recognizing a situation in which taking short-term measurements of SOM might be useful. Even in less dynamic situations, such as conventionally managed monocultures or sites under fallow, frequent measurements would permit the temporal course of a long-term change to be reported, i.e., the specific years or events during which most change has taken place.

5. Conclusions

[31] Soil organic matter (SOM) as a whole is often regarded as slow to experience noticeable changes, and even in agroecosystems, long periods of time are considered prerequisite to documenting significant effects. The amount of C in soil is indeed large, and long-term changes are subtle in the majority of cases, including SAFS. However, sites designed for long-term study, once established or identified, should not necessarily be ignored until "enough" years have passed so that whole soil C measurements can be considered, if such data are of interest. At SAFS, for example, net changes since the establishment of the site fail to disclose a timeline marked by repeated rises, falls, and plateaus in soil C content and composition. Parallel to changes in soil C content, short-term fluctuations in soil C composition can be conveniently evaluated using the well-known ^{13}C natural abundance approach, in spite of the fact that many years and "clean" (i.e., one input) sites have typically been preferred for applying this technique.

[32] In the midst of emphasis on long periods when characterizing different ecosystems, managed or unmanaged, and the prestige of soil C data obtained after many years of study, it may be tempting to compile only clean, comprehensive results not subject to the chaos of short-term fluctuations. The ideal approach, however, may be to consider both long-term and short-term data. Long-term data indicate the direction and cumulative degree of change in a system as a result of many years under certain conditions. Short-term soil C data, while never a substitute for results obtained after many years, can provide complementary information rather quickly, describing the progress of the SOM reservoir as a whole along an extended trend. Long-term trends are, after all, ultimately the repetition of short-term behavior. Recognizing the immediate effect of each change in external conditions also permits the most important aspects of a system to be identified, i.e., particular events or management decisions which are contributing most to long-term trends, as well as the overall extent of C storage or turnover taking place during each season. Furthermore, short-term soil C data are useful for strengthening long-term simulation models, which depend primarily on seasonally dynamic conditions but must often be fit against temporally limited soil C data. The approach presented here can advance our understanding of SOM dynamics in surface soils and encourage the use of ^{13}C natural abundance measurements together with soil C measurements in whole soil, both easily obtained primary data, as a useful part of characterizing these dynamics.

[33] **Acknowledgments.** The collection of archived soil samples by SAFS staff is gratefully acknowledged. David Harris of the UC Davis Stable Isotope Facility performed ^{13}C analyses. The constructive review of this manuscript is also gratefully acknowledged.

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