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Use of 13C and 15N natural abundance techniques to characterize carbon and nitrogen dynamics in composting and in compost-amended soils

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Abstract

Isotope fractionation during composting may produce organic materials with a more homogenous $\delta^{13}C$ and $\delta^{15}N$ signature allowing study of their fate in soil. To verify this, C, N, $\delta^{13}C$ and $\delta^{15}N$ content were monitored during nine months covered (thermophilic; $>40\,^{\circ}\text{C}$) composting of corn silage (CSC). The C concentration reduced from 10.34 to 1.73 g C (g ash)$^{-1}$, or 83.3%, during composting. Nitrogen losses comprised 28.4% of initial N content. Compost $\delta^{13}C$ values became slightly depleted and increasingly uniform (from $-12.8\pm0.6\%o$ to $-14.1\pm0.0\%o$) with composting. Compost $\delta^{15}N$ values (0.3 ± 1.3 to $8.2\pm0.4\%o$) increased with a similar reduced isotope variability.

The fate of C and N of diverse composts in soil was subsequently examined. C, N, $\delta^{13}C$, $\delta^{15}N$ content of whole soil (0–5 cm), light (<1.7 g cm^{-3}) and heavy (>1.7 g cm^{-3}) fraction, and (250–2000 μm; 53–250 μm and <53 μm) size separates, were characterized. Measurements took place one and two years following surface application of CSC, dairy manure compost (DMC), sewage sludge compost (SSLC), and liquid dairy manure (DM) to a temperate (C$_3$) grassland soil. The $\delta^{13}C$ values and total C applied (Mg C ha^{-1}) were DM ($-27.3\%o$; 2.9); DMC ($-26.6\%o$; 10.0); SSLC ($-25.9\%o$; 10.9) and CSC ($-14.0\%o$; 4.6 and 9.2). The $\delta^{13}C$ of un-amended soil exhibited low spatial ($-28.0\%o\pm0.2$; $n=96$) and temporal ($\pm0.1\%o$) variability. All C$_4$ (CSC) and C$_3$ (DMC; SSLC) composts, except C$_3$ manure (DM), significantly modified bulk soil $\delta^{13}C$ and $\delta^{15}N$. Estimates of retention of compost C in soil by carbon balance were less sensitive than those calculated by C isotope techniques. One and two years after application, 95 and 89% (CSC), 75 and 63% (SSLC) and 88 and 42% (DMC) of applied compost C remained in the soil, with the majority (80–90%) found in particulate (>53 μm) and light fractions. However, C$_4$ compost (CSC) was readily detectable (12% of compost C remaining) in mineral (<53 μm) fractions. The $\delta^{15}N$-enriched N of compost supported interpretation of $\delta^{13}C$ data. We can conclude that composts are highly recalcitrant with prolonged C storage in non-mineral soil fractions. The sensitivity of the natural abundance tracer technique to characterize their fate in soil improves during composting, as a more homogeneous C isotope signature develops, in addition to the relatively large amounts of stable C applied in composts.

1. Introduction

Composting is the most popular technology for treatment of organic wastes, as it can be applied to process wastes of widely varying origin, including animal manures and mortalities, sewage sludges, and municipal and industrial wastes (Hoitink and Keener, 1993; Kashmanian et al., 2000). Composting has long been used for management of manure on farm (Kashmanian and Rynk, 1995) and is a required practice under organic agriculture production protocols in Canada (Canadian General Standards Board, 1991). The agronomic value of compost and its beneficial or detrimental effects on soil and the environment is closely linked to the nature and dynamics of its constituent organic matter (He et al., 1995). However, a technical difficulty has been the lack of a reliable and inexpensive methodology to examine the fate of compost in soil and to quantify compost effects on soil organic matter (SOM) (Angers and Carter, 1996; Rochette

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and Gregorich, 1998). This would improve our understanding of how the biochemical composition of these materials impacts on their partitioning into selected SOM pools, and how these specific inputs influence SOM decomposition in a manner distinct.

The natural abundance stable isotope ^{13}C (or $\delta^{13}C$) tracer technique utilizes the differences in $\delta^{13}C$ range between C_3 (−23 to −30‰) and C_4 plants (−9 to −19‰) to characterize the dynamics of 'native' and 'new' soil organic carbon (SOC). Since pioneered by Cerri et al. (1985) the technique has been widely used to study the impact on soil C following shifts between C_3 and C_4 vegetation (Balesdent et al., 1988; Angers et al., 1995; Drinkwater et al., 1998; Wanniarachchi et al., 1999). Applications of this $\delta^{13}C$ technique are diverse (Balesdent and Mariotti, 1996; Boutton, 1996). Organic amendments often supply much greater C inputs to soil than are derived from crop residues (Gerzabek et al., 2001). However, relatively few studies (Bol et al., 2000, 2004; Glaser et al., 2001) have applied the $\delta^{13}C$ technique to improve our understanding of the transformation, utilization and stabilization of amendment carbon in soil. Gerzabek et al. (2001) attempted to describe the long-term (46y) SOC dynamics in C_3 soil in response to a range of organic C_3 amendments including green manure (−27.3±1.1‰), sewage sludge (−25.5±0.2‰), manure (−27.5±0.8‰) and peat (−25.6±0.4‰). However, application of the technique was acerbated by 1) lack of distinction in $\delta^{13}C$ between amendment and soil (−26.3‰) and 2) the relatively high variability of $\delta^{13}C$ signature of the added materials. However, the high degree of microbial processing occurring during composting of organic amendments may reduce the inherent variability of their ^{13}C signature, an aspect of composting which remains unexamined. Physical separation of organic matter in to densiometric and size-fractions has been used to describe the fate of isotopically labeled plant residues (Aita et al., 1997) and non-labeled C from various organic amendments including composts (Carter et al., 2004). Physical fractionation methods have also been combined with tracer techniques in attempts to describe the fate of manure and organic amendment C derived from C_4 (Amelung et al., 1999; Bol et al., 2004) and C_3 sources (Gerzabek et al., 2001).

Labeling homogeneously all N fractions of manure or compost is difficult. Thomsen and Olesen (2000) produced composted and uncomposted manures labeled with ^{15}N in the urine, faeces or straw fractions in sufficient quantities for a soil incubation study by feeding sheep ^{15}N-enriched labeled forage. Better agreement, in the proportion of manure N mineralized in soil calculated by both N balance and ^{15}N techniques was obtained for the composted compared to the un-composted manure. Munoz et al. (2003) monitored for three years the fate of manure N in soil and crop after applying dairy manure cross-labeled in urine and feces to field microplots. Over 18% of applied manure ^{15}N was recovered in the corn crop, while 46%

remained in the soil. The expense and difficulty in producing a uniformly labeled manure with enriched ^{15}N was seen as a significant drawback. Attempts to use the natural abundance of N ($\delta^{15}N$) as an in situ label to characterize manure N dynamics may be limited by the variability in ^{15}N content of inorganic and organic N fractions and subsequent changes in the tracer signature in soil (Hogberg, 1997). Glaser et al. (2001) found that the enrichment of 9‰ in $\delta^{15}N$ of slurry N relative to background soil allowed for a 'tentative' estimate of slurry-derived N remaining ($\sim 26\%$) in soil after 2 weeks. However, the effect of composting on the $\delta^{15}N$ signature of manures and waste materials, remains unexamined. Nitrogen in stabilized compost is predominately ($>90\%$) present in the organic form (Lynch et al., 2004; Kirchmann and Witter, 1989). Isotope fractionation during composting, as a result of N losses and /or microbially-mediated turnover of N, may result in an enriched, homogeneous, and relatively stable $\delta^{15}N$ signature with which to trace organic amendment N in soil.

The following study examined (1) the effect of composting on compost feedstock C and N content and isotope signature, and (2) whether the fate of C_4 and C_3 compost C and N in soil could be characterized using $\delta^{13}C$ and $\delta^{15}N$ techniques in combination with soil physical fractionation methods.

2. Materials and methods

2.1. Characterization of changes in C and N isotope signature during composting

Commencing in December, 1998, a total of 30 Mg of corn silage was composted for 9 months in a covered concrete silo and turned frequently ($\sim$ monthly). Because of its C:N ratio ($\sim 30:1$), high available C content, and particle size distribution, corn silage composts readily. All feedstock components were derived from one C_4 crop source, and no further additions were required. This material was considered an ideal feedstock to model C and N isotope dynamics during composting, and to provide a double-labeled ($\delta^{13}C$, $\delta^{15}N$) source to examine the fate of it's C and N in soil. Prior to composting, $\delta^{13}C$ values for readily identifiable plant structural components (corn cob, pith, leaf/sheath, seed) fell within a narrow range ($<1‰$) ($n=4$ for each tissue; data not shown). Compost pile temperatures were determined monthly using a compost dial thermometer. Composite compost samples (~ 7 kg; $n=4$) were recovered approximately bi-monthly. Compost pH was measured in a 1:2 slurry of 25 g compost and water. Water soluble extracts were obtained using a modification of the method of Chefetz et al. (1998). Approximately 500 g (fr. wt.) compost was extracted in deionized water by shaking horizontally (125 rpm) for 1 h in a 2 l plastic container, using a 1:2 compost/water ratio. The suspension was centrifuged (30 mins at 10,000 g) and the supernatant