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Effect of fertilization on decomposition of ^{14}C labelled plant residues and their incorporation into soil aggregates

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ABSTRACT

Returning crop residues to soil helps to maintain soil C stocks. Organic C stocks and microbial biomass are important factors controlling the decomposition or retention of crop residues in soil and the formation of aggregates. Little is known about the specific contribution of crop residues to soil aggregate size fractions in the framework of long-term fertilization. This study investigated the effects of long-term fertilization on the decomposition of ^{14}C-labelled plant residues and their incorporation into soil organic matter (SOM) of different aggregate size fractions. Soils were collected from 0–10 cm in the Ap horizon of a long-term (since 1988) field experiment at Grossbeeren (Germany). The following four fertilization treatments were used: 1) without fertilization or manuring (Control), 2) nitrogen applied by mineral fertilizer (N), and 3) manure with low (M) and 4) high (2 M) application doses. Soils were incubated for 100 days at 20 °C, with or without ^{14}C-labelled plant residue. The incorporation of ^{14}C into three aggregate size fractions–large macroaggregates (2–1 mm), small macroaggregates (1–0.25) and microaggregates (<0.25 mm)–was analyzed.

After 15 days of incubation, 44–57% of plant residue was mineralized in the order: M > N > control soil > 2 M. Adding plant residues increased soil β-glucosidase activity and microbial biomass C. On day 16 of incubation, more residue ^{14}C was retained in small and large macroaggregates than in microaggregates in the control soil. In contrast, in fertilized soils the reverse was measured. Additionally, N, M and 2 M soils showed significant differences by incorporation of ^{14}C in microbial biomass and β-glucosidase activity in different aggregate size fractions. The results imply that long-term fertilization significantly increased the residue ^{14}C retention in microaggregate size fractions and its decomposition in soils.

1. Introduction

Land-use is the most important factor affecting the soil organic carbon (C_{org}) stock. The crop residue inputs in soil influence aggregate structure by changing C_{org} (Tisdall and Oades, 1982; Haynes and Swift, 1990; Hulugalle and Cooper, 1994). At the same time, aggregation affects C_{org} storage by occluding organic materials, making them inaccessible to degrading organisms and their enzymes (Sollins et al., 1996). Tillage disruptions of soil aggregates, however, expose such physically protected organic material (Paustian et al., 2000; Six et al., 2000) and enhance C mineralization and/or CO_2 fluxes (Elliott, 1986; Reicosky et al., 1995). Therefore, understanding the key factors and processes controlling aggregation and C_{org} storage and turnover is critical because any changes in C_{org} could significantly affect the CO_2 levels in the atmosphere.

Various fertilizer inputs such as mineral fertilizers and manure are used mainly to increase crop yield and thus the amount of crop residue, much of which is returned to the soil. Therefore, intensive crop cultivation with high inputs of organic fertilizers results in high organic matter input, which acts as a binding agent for aggregate formation. Aggregates are composed of mineral particles and binding agents (Tisdall and Oades, 1982; Haynes and Swift, 1990) and the initial unit is termed microaggregate. According to Tisdall and Oades (1982), soil microaggregates (<250 μm) are bound together by organic compounds of different origin to form stable macroaggregates (>250 μm). Fresh organic materials such as plant residues have abundant readily decomposable C. They therefore increase aggregate stability (De Gryze et al., 2005; Abiven et al., 2007) by enriching young organic matter in macro- versus microaggregates (e.g. Puget et al., 1995; Jastrow et al., 1996; Six et al., 2000; John et al., 2005; Yamashita et al., 2006; Helfrich et al., 2008). Little information, however, is available on how and to what extent plant residues influences aggregation and on the partitioning of recently added C within aggregate size fractions during decomposition. One of our hypotheses is that the high manure doses accelerate C stabilization in soil more than the average dose.

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The first aim of the present study was therefore to gain quantitative knowledge about the stabilization of added plant residues in soil aggregates. This information is necessary to understand, assess and predict the effects of plant residue on C storage in aggregate size fractions.

Soil microbes decompose added plant residues. These microbes derive their energy by oxidizing organic C. The plant residue C passes through the microbial biomass at least once as it is transferred from one C pool to another and finally mineralized to CO_2 (Ryan and Aravena, 1994). The remaining microbially undecomposed part of the plant residues contribute to the soil C stock (Lorenz and Lal, 2005). Land-use management with fertilization or manuring affects the residue decomposition rate and thus C_{org} turnover (Paustian et al., 1997). This requires knowledge about the decomposition mechanism of the added plant residue as influenced by long-term fertilizer management strategies. This, in turn, is necessary to identify the pathways of C sequestration in soils. In order to differentiate and quantify C decomposed from added plant residue, ^{14}C-labelled plant residues were used in an incubation experiment with soils from a long-term cultivated experiment with different land-use practices. We investigated aggregate formation during litter decomposition and the role of newly formed aggregates in storing plant-derived C. This study therefore (i) evaluates the long-term management effect on plant residue decomposition, (ii) assesses the plant residue C stability in soil by analyzing soil microbial biomass and enzyme activity, (iii) assesses the amount of stabilized plant residue C added to aggregate size classes, and (iv) quantifies the relationship between plant residue C input and C sequestration in soil.

2. Materials and methods

2.1. Soil and long-term field experiment

Soil samples were taken in January 2008 from the 0–10 cm layer of a sandy Cambisol at the experimental plots of the long-term field trial "Trasse 2" of the Institute of Vegetable and Ornamental Crops (IGZ), Grossbeeren, Germany (52°20′56.70″ N, 13°19′07.90″ E). The climate conditions (1973–2002) of the site are characterized by a mean annual temperature of 8.8 °C and an average rainfall of 520 mm y^{-1} plus 150 mm y^{-1} irrigation water. The soil pH ($CaCl_2$) was 6.6, and sand and clay contents of the soil were 81 and 5%, respectively. The soil had a bulk density of 1.59 g cm^{-3}.

Soil samples were selected from four treatments having a different fertilization history during 20 years: 1) control soil (without mineral and manure fertilization), 2) with mineral nitrogen application 270 kg N ha^{-1} a^{-1} (N), 3) farmyard manure (FYM) application 30 t ha^{-1} a^{-1} (M) and 4) FYM application 60 t ha^{-1} a^{-1} (2 M). Before ploughing, the respective amounts (30 and 60 t ha^{-1}) of well-decomposed FYM was applied to the specified plots (size: 4.5 m x 5.0 m) of the experiment. During the experimental period, the mean dry matter concentration of fresh FYM was 0.22 g g^{-1} and the mean C content was 0.31 g g^{-1} (oven-dry basis). Mineral N fertilizer was applied as calcium ammonium nitrate at a high N level corresponding to 270 kg N ha^{-1} a^{-1}. The crops grown annually were white cabbage (*Brassica oleracea* L. var. capitata f. alba), carrot (*Daucus carota* L.), cucumber (*Cucumis sativus* L.), leek (*Allium porrum* L.), and celery (*Apium graveolens* L. var. rapaceum Mill.). At harvest, all the above-ground plant material (yield plus crop residue) was removed from the plots. After sampling, the soil was air-dried (30 °C), thoroughly mixed and sieved (2 mm), after which all visible roots were carefully removed both with the electrostatic method (Kuzyakov et al., 2001) and manually by tweezers.

2.2. Incubation

The laboratory incubation was conducted in closed vessels at 20 °C for 100 days. Forty grams of air-dried soils were weighed into 250 ml glass vessels (Schott Duran, Mainz, Germany). The experiment was set up with eight treatments in triplicates including two factors. The first factor was four land-use managements: C, N, M and 2 M (described above). The second factor was ^{14}C-labelled plant residue additions: No residue (- residue) or 20 mg ^{14}C-labelled plant residue (+ residue) (36.5% C and 2.9% N) ground with a ball mill (Retsch) were added and thoroughly mixed with the soil of the four land-use treatments. The ^{14}C labeled residues (22 Bq mg^{-1}) were produced by labelling *Lolium perenne* by 7 pulses in $^{14}CO_2$ atmosphere (for details see Kuzyakov et al., 2002). The soil moisture was kept at 70% of its water holding capacity (24.4%) with deionized water. Small vials with 3 ml of 1.0 M NaOH were placed in the vessels to trap CO_2. The traps were changed daily in the initial days and then 3 times per week throughout the incubation period. Additional triplicate blank vessels containing only the vials with NaOH served as controls to account for the CO_2 trapped from the air inside the vessels.

2.3. Aggregate-size fractionation at optimal soil moisture

Before incubation and sixteen days after the start of incubation, the soil samples were prepared for aggregate fractionation. Aggregates were isolated according to Kristiansen et al. (2006): 40 g were transferred to a nest of sieves (1 and 0.25 mm) and shaken for 90 s and the 1–2 mm aggregates were collected (large macroaggregates). The same procedure was done for the material retained on the 0.25 mm sieve, isolating the 1–0.25 mm aggregate-size class (small macroaggregates). The remaining material passed through the 0.25 mm sieve was identified as the <0.25 mm aggregate class (microaggregates). The recovery after sieving was about 98% of soil weight (Table 1). Preliminary tests showed that the sieving duration was sufficient to quantitatively separate the various aggregate-size classes while minimizing aggregate abrasion during sieving (Dorodnikov et al., 2009).

Table 1
Aggregate size fractions of the soil as depending on 20 years of fertilization (0–10 cm) at the long-term field trial Trasse-2 in Grossbeeren.

Aggregate size class	Control[a]	N	M	2 M
	% of soil mass			
Large macroaggregates: 1–2 mm	16.4 ± 2.0	12.8 ± 1.6	16.1 ± 1.0	16.5 ± 3.9
Small macroaggregates: 1–0.25 mm	35.1 ± 1.5	44.8 ± 0.1	42.1 ± 3.0	51.1 ± 1.4
Microaggregates: <0.25 mm	47.6 ± 1.3	41.1 ± 1.6	40.4 ± 2.1	31.7 ± 5.3
Sum of three fractions	99.0	98.7	98.5	99.2

N: mineral (N) fertilized soil, M: manure amended soil, 2 M: manure amended in double manure dosage.
[a] mean ± standard deviation.