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Original article

Influence of tillage on degradation kinetics using the litterbag method

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ABSTRACT

A litterbag experiment was carried out in a tillage trial near Göttingen, Germany, comparing the long-term effects of mouldboard plough and rotary harrow on organic matter dynamics. The aim was to investigate the C loss and N balances in litterbags filled with N-poor, lignin-rich wheat straw and N-rich, lignin-poor maize residues, simulating the properties of green manures. The litterbags were buried at 0–5 and 15–20 cm depth and one fourth of them were removed after 3, 6, 9, and 12 months, respectively. The C loss rates, corrected for soil input into the litterbags, were significantly affected by tillage and bury depth and showed significant litter material × bury depth interactions. These were caused by generally higher C loss rates in the plough treatment, especially at 15–20 cm depth, and in the litterbags with maize residues. More soil was transferred to the litterbags in the plough treatment than in the rotary harrow treatment and more soil was found in the litterbags at 0–5 cm than at 15–20 cm depth. A smaller amount of stable aggregates in the surrounding soil is the most plausible explanation for this higher soil input. Nearly 40% of maize residue C was lost in the first three months from November to February, followed by a further exponentially decreasing loss of 40% over the next 9 months. Almost no wheat straw C was lost in the first three months, followed by a nearly linear loss of 60% over the next 9 months. The N balance showed strong N losses in the litterbags with maize residues for all exposure periods. In contrast, the N balance was always positive for wheat straw. The N balances, corrected for soil input, revealed significant bury depth effects and exposure period × bury depth interactions, but no significant tillage effects.

1. Introduction

In two long-term tillage experiments, the replacement of the mouldboard plough by a rotary harrow led to a significant, but moderate increase in soil organic C and total N and to a strong increase in microbial biomass C and N [16,42]. A reduction in tillage intensity may thus be an important tool for sequestering CO_2 in soil organic C as a means of combating global warming [26]. However, not all experiments have revealed a significant increase in soil organic matter after reducing tillage intensity [1]. The increase in soil organic C and total N stocks may be caused by the occlusion of organic matter in soil aggregates, reducing microbial access and thus decomposition rates [17,22]. Moreover, such a process may also lower the microbial turnover. However, this lowering might also be caused by microbial N deficiency. Shallow tillage with a rotary cultivator had much stronger negative effects on NH_4 mineralization than on basal respiration, during laboratory incubation [1]. Lower N mineralization in the field might be the reason for N tillage-induced deficiency symptoms in crops [1] and for an increased fertilizer demand in tillage systems without mouldboard plough [6].

The use of litterbags is a common method for monitoring decomposition of tree litter in forest ecosystems [24]. Litterbags have been used less frequently for assessing human impact under field conditions, such as tillage management in arable ecosystems [25]. Few studies have investigated the differences in decomposition dynamics between a surface application (no-tillage) and buried residues [4,20,41]. Generally, the litter buried in the soil decomposed faster, due to the more intimate contact to soil particles and soil-derived decomposers [35]. Here, plant residues were intensively analyzed after recovery from litterbags exposed for up to 12 months in a long-term tillage trial near Göttingen, Germany,

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comparing the long-term effect of mouldboard plough and rotary harrow since 1967. The aim was to investigate C loss and N balance in the litterbags filled with N-poor, lignin-rich wheat straw and N-rich, lignin-poor maize residues, simulating the properties of green manures. The litterbags were buried at 0–5 and 15–20 cm depth, with the aim of investigating whether differences in microbial biomass cause any effect on C loss and N balance.

2. Materials and methods

2.1. Experimental site and investigation design

Two tillage systems were investigated at the research site Hohes Feld (51° 37′ N, 9° 53″ E, 151 m ASL) close to Göttingen (Lower Saxony, Germany), which was established in 1967. The average mean annual precipitation is 645 mm with a mean annual temperature of 8.4 °C. The mean texture at 0–30 cm depth was 17.2% clay, 66.4% silt, and 16.4% sand at the site Hohes Feld [8]. The mean soil pH-H_2O was 7.5. The site had been mouldboard ploughed for many years before the experiments started. One tillage treatment was regularly mouldboard ploughed down to 25–30 cm depth in autumn. The other tillage treatment consisted of shallow cultivation down to 5–8 cm depth with a rotary harrow for stubble cultivation and seedbed preparation [9,37]. The experimental design was a split plot design with three replicate plots (12.8 × 36 m). The crop rotation was generally based on cereals. However, peas (*Pisum sativum* L.) were cultivated in 2004, winter wheat (*Triticum aestivum* L.) in 2004/2005, maize (*Zea mays* L.) in 2006, and broad beans (*Vicia faba* L.) in 2007. The experimental sites were fertilized on average with 160 kg N ha^{-1} a^{-1} over the previous 10 years, except in the case of legume cultivation, where no fertilizer was applied. Additionally, an average 20 kg P, 90 kg K, and 10 kg Mg ha^{-1} a^{-1} were applied from 2005 to 2007. The chopped straw remained on the plots.

2.2. Litterbags and soil samples

Polyamide litterbags (5 × 20 cm; 1 mm mesh) were filled with 5 g dry matter of green-harvested maize (*Zea mays* L.) leaves and wheat (*Triticum aestivum* L.) straw. The litter material was dried (60 °C), chopped < 5 mm (mill type SM1, Retsch, Hanau, Germany) and sieved > 2 mm. Litterbags were closed with a plastic clip and buried vertically in the soil at 0–5 and 15–20 cm depth after sowing of winter wheat on the 8th, 12th, and 14th of November 2007. For each treatment (tillage treatment: rotary harrow versus mouldboard plough; litter material: maize residues versus wheat straw; bury depth: 0–5 versus 15–20 cm; and exposure period: 3, 6, 9, and 12 months), six litterbags were buried at each of the three field replicates. After an exposure period of 3, 6, 9, and 12 months in the field (4th of February 2008, 8th of May 2008, 11th of August 2008, and 3rd of November 2008), one fourth of the litterbags in each treatment were recovered and stored at 4 °C until further analysis. Soil loosely adhering to the litterbags was removed with a knife prior to opening the bag itself. Any visible roots and fauna that had penetrated the litterbag were removed. The litterbag material was dried at 40 °C for 48 h and ground in an agate stone mill. On each litterbag sampling date, a composite soil sample was taken out of three subplots from each field replicate for both tillage treatments and both bury depths (0–5 and 15–20 cm).

2.3. Analysis

Total C and total N in soils and straw were determined using a Vario Max CN analyzer (Elementar, Hanau, Germany). Soil organic C content was measured as total C content minus carbonate C content, which was measured gas-volumetrically after the addition of HCl. Ash content was determined by heating 1 g of sample at 550 °C for 6 h. Soil microbial biomass C was estimated by the fumigation-extraction method [44] as described by Heinze et al. [16] and as E_C/k_{EC}, where E_C = (organic C extracted from fumigated soils) − (organic C extracted from non-fumigated soils) and k_{EC} = 0.45 [46]. Soil temperature was measured at 10 cm depth with a continuously reading data-logger. Precipitation data was obtained from the German Meteorological Service (DWD). Soil moisture was measured gravimetrically after drying at 105 °C, using a 250 cm^{-3} steel core as a sampling device at 0–10 cm depth.

2.4. Calculations and statistical analysis

The results presented in the tables are arithmetic means and expressed on an oven-dry basis (about 24 h at 105 °C). Equations (1) and (2) describe the calculation of the remaining C in percent of added C, without and with correction of the input of soil-derived C or N, respectively:

$$\text{C remaining} = (A \times B)/(F \times G) \times 100 \quad (1)$$

$$\text{C remaining, corrected for input of soil C} = (A \times B - C/D \times E \times F)/(F \times G) \times 100 \quad (2)$$

A: dry weight of the litterbag at the sampling date in g
B: total C content in the litterbag material at the sampling date in mg g^{-1} dry weight (maize residues 389.4 and wheat straw 385.6)
C: ash balance, equation (3)
D: ash content of the surrounding soil in mg g^{-1} dry weight
E: total C content of the surrounding soil in mg g^{-1} dry weight
F: initial weight of the litterbag in g
G: total C content in the initial litterbag material in mg g^{-1} dry weight

Equation (3) describes the calculation of the ash balance in g g^{-1} dry weight added:

$$\text{Ash balance} = (A \times H - F \times I)/F/1000 \quad (3)$$

A, C, F: see equations (1) and (2)
H: ash content in the litterbag material at each sampling date in mg g^{-1} dry weight
I: ash content in the initial litterbag material in mg g^{-1} dry weight (maize residues 195.0 and wheat straw 197.8)

Equations (4) and (5) describe the calculation of the N balance in g g^{-1} dry weight added, with and without correction of the input of soil-derived N, respectively:

$$\text{N balance} = (A \times I)/(F \times J) \times 100 \quad (4)$$

$$\text{N balance, corrected for input of soil N} = (A \times J - F \times K)/F - (C/D \times L) \quad (5)$$

A, C, D, F: see equations (1) and (2)
J: total N content in the litterbag material at the sampling date in mg g^{-1} dry weight
K: total N content in the initial litterbag material in mg g^{-1} dry weight (maize residues 18.6 and wheat straw 2.7)
L: total N content of the surrounding soil in mg g^{-1} dry weight