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Fifty years of crop residue management have a limited impact on soil heterotrophic respiration

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ABSTRACT

The impacts of crop residue management on soil microbial biomass, labile carbon and heterotrophic respiration (HR) were assessed at a long-term experimental site in the Hesbaye region in Belgium. Three treatments, residue export (RE), farmyard manure addition (FYM) and residue restitution after harvest (RR), have been applied continuously since 1959. The soil is a Eutric Cambisol with, in 2010, significantly different total soil organic carbon contents of 4.4, 5.1 and 5.9 $\mathrm{kg\,C\,m^{-2}}$ under the RE, RR and FYM treatments, respectively. Manual field HR measurements were carried out during the 2010 and 2012 crop seasons using a dynamic closed chamber system. Microbial biomass, labile C content and metabolic diversity of soil bacteria were assessed in spring 2012.

Fifty-one years after the beginning of the treatments, residue management had a limited impact on HR. Based on daily averaged values, the treatment had a significant impact ($\alpha = 10\%$) in 2012 but not in 2010. Based on the individual measurement dates, the treatment impact was less obvious in 2012; with the observation of a significant impact ($\alpha = 10\%$) on HR in only 7% and 36.8% of the measurement dates in 2010 and 2012, respectively. Labile C and microbial biomass were significantly lower in the RE treatment than in FYM and RR. Residue management had no significant effect on cold-water extracted carbon and metabolic diversity of heterotrophic soil bacteria. The limited impact of residue management on HR could be explained by (i) the relatively low amounts of recent above-ground crop inputs, (ii) the large proportion of below-ground residues and other non-exportable above-ground residues reducing the potential differences between treatments and (iii) the relatively large spatial variability of HR.

In conclusion, carbon losses due to heterotrophic respiration did not differ between RE, FYM and RR treatments in the studied soil. This contrasts with the different soil organic carbon contents observed in these three treatments after 50 years of experiment. Further investigations regarding the reduction of spatial variability and the potential roles played by organic matter protection within aggregates and biochemical composition of inputs are needed.

1. Introduction

Agricultural soils have frequently been reported to lose large amounts of carbon (C) (Goidts and van Wesemael, 2007; Janssens et al., 2003; Smith, 2004). Soil C loss negatively affects soil stability (Lal, 2004), which is harmful to agricultural productivity. It also results, through the process of heterotrophic respiration (HR) releasing carbon dioxide (CO_2) into the atmosphere, in atmospheric CO_2 concentration level increase, which accelerates global warming. CO_2 emissions due to HR could become more important with increasing temperatures related to climate change (Davidson and Janssens, 2006). Crop management has a high potential to mitigate soil C loss. According to Smith (2012), crop management techniques could actually constitute more important drivers of SOC stock changes and CO_2 emissions in croplands than climatic effects. Future management practices should maintain good soil properties (e.g., fertility, stability, water-holding capacity) and help mitigate climate change (Smith, 2012).

Long-term field experiments have been initiated around the world to assess the impact of crop management, comprising residue and soil management techniques, on SOC stocks and greenhouse gas emissions. Although long-term residue management has been reported to have a large impact on SOC stocks (e.g. Smith et al., 1997 and, specifically about the site investigated in this study, Buysse et al., 2013), its influence on HR (more particularly the relationship between the amounts of crop residue and the HR rates) is not clear

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(Chirinda et al., 2010; Duiker and Lal, 2000; Jacinthe et al., 2002; Mu et al., 2008). HR is driven by many interacting factors, such as substrate quantity and quality, microbial biomass, soil texture, temperature and water content. The large spatio-temporal variability of each HR driving variable, and particularly the amount of available substrate, contributes to the difficulty to predict HR under different crop management scenarios. In order to take this variability into account, the question of crop management influence on HR at the ecosystem spatial scale needs be addressed using field measurements (Chirinda et al., 2010; Duiker and Lal, 2000; Mu et al., 2008; Vinther et al., 2004). This preserves soil structure irregularities, organic matter protection micro- and macro-sites and wind effects, all potentially driving spatial variability (Gesch et al., 2007). According to de Campos et al. (2011) the representativeness of management practices could indeed be affected by sample handling in laboratory measurements.

In temperate ecosystems, temperature is generally considered as the main driving variable of HR (Davidson and Janssens, 2006; Kätterer et al., 1998; Lloyd and Taylor, 1994). To a lesser extent in these ecosystems, soil water content can also affect the process, particularly when dry conditions make substrate less available to micro-organisms (Luo and Zhou, 2006). Besides, both input quantity and quality are important characteristics driving HR fluxes. It might be expected that higher carbon inputs to the soil results in higher HR (Jacinthe et al., 2002). Furthermore, residue quality and accessibility affect the ability of micro-organisms to decompose substrates. Residue input quantity and/or quality can also influence the microbial populations, through changes in microbial biomass or adaptive changes within the metabolic diversity of the microbial community (Calbrix et al., 2007; Govaerts et al., 2007). In the present study, three residue management treatments were selected, characterized by different input quantities and qualities: residue export, residue restitution and farm yard manure input. The most important particularity of this study is the connection between the HR rates measured at the crop season scale and SOC changes observed in the long-term.

This study was implemented on the basis of a long-term residue management experiment where a previous study (Buysse et al., 2013) showed that the treatment had a significant impact on SOC stocks in the long-term (51 years). The objectives of the present study were (i) to assess the impacts of crop residue management (including farmyard manure input) on HR and (ii) to test if more labile soil organic C fractions are affected by long-term residue management and (iii) to try to link the HR rates measured at the crop season scale and SOC changes observed in the long-term. For this purpose, HR was measured in the field over two crop seasons and laboratory measurements (microbial biomass, labile C and microbial diversity) were carried out to add complementary data to HR measurement campaigns.

2. Materials and methods

2.1. Site description

The Longs Tours site is situated in the Hesbaye region in Belgium (50°33′28″ N, 4°43′39″ E, 170 m asl). The climate is temperate maritime with, over the 1959–2012 period, a mean annual air temperature of 9.4 °C and an average annual rainfall of 798 mm. The study field is a fairly flat rectangular area (360 m × 120 m). The soil is classified as a Eutric Cambisol (IUSS Working Group WRB, 2006); the clay, silt and sand proportions are 12, 85 and 3%, respectively. The site is situated at 2 km from the Lonzée Terrestrial Observatory (LTO), fully equipped for measuring CO_2, water vapor and energy fluxes, as well as micrometeorological variables (Moureaux et al., 2006).

The long-term experiment was initiated in 1959 to investigate the influence of residue management on crop yield, SOC content and soil physical properties. The site was part of the Global Change and Terrestrial Ecosystems Soil Organic Matter Network (GCTE SOMNET), established in 1995, assessing the effects of land use changes on soil organic matter, agricultural practice and climate. Six residue management treatments were applied to a total of 36 rectangular plots (70 m × 10 m; 6 replicates per treatment) (Fig. 1). All plots were ploughed every year to a depth of 25 cm. Between 1959 and 1974, the whole field was cultivated following a 4-year rotation cycle (sugar beet–cereal [oats or winter wheat]–legume [horsebean]–cereal [winter wheat or barley]). From 1975 onwards, a 3-year rotation cycle (sugar beet–winter wheat–winter barley) was followed.

Among the six initial treatments, we selected the three management practices most contrasted in carbon input and residue type. For residue export (RE), most aerial residues (except stubble which may represent about 30% of above-ground residues, the exact proportion being not measured) were removed after harvest and no other organic C was added to the soil. Farmyard manure (FYM) consisted in the application of fresh manure (30–60 t ha^{-1}) to the soil once every 4 (until 1975) or 3 (from 1975 onwards) years, at the beginning of each sugar beet crop season. In the residue restitution treatment (RR), all crop residues were returned to the soil at the end of the cropping seasons. Catch crops (vetch or mustard) were grown only in the RR treatment, during the fallow periods preceding the sugar beet crops, every 3 years from 1970. Average total C input amounted 315 ± 76, 472 ± 82 and 487 ± 93 gC m^{-2} $year^{-1}$ in the RE, FYM and RR treatments, respectively (Table 1). In May 2010, 51 years after the start of the long-term experiment, SOC was significantly higher under FYM, compared to RE and RR (sampled in the horizon 0–25 cm). More details about crop details and the long-term soil carbon budget at the Longs Tours site can be found in Buysse et al. (2013).

2.2. Field HR flux measurements

Heterotrophic respiration was measured in three replicate plots of the three selected treatments during the 2010 and 2012 crop seasons (Table 2, Fig. 1). These two measurement campaigns corresponded to periods before and after the farmyard manure spreading to the field (10 August 2011). All plots were situated in a well-drained part of the field. HR measurements were performed within one square area (9 m^2) in each plot. In 2010, glyphosate was applied to the young winter wheat shoots 2 weeks before the measurements, a delay allowing the microbial population to recover its original activity (Haney et al., 2002). Glyphosate application may cause a small extra CO_2 flux emission due to the decomposition of the young winter wheat shoots and roots. However it is important to state that this was applied similarly in all three treatments, which then makes possible to compare the crop seasonal CO_2 emissions from the three treatments on a same basis. In 2012, the young sugar beet shoots were removed manually. The weeded areas differed in 2010 and 2012 in order to prevent a long-term bias due to the experimental set-up.

Additionally, the short-term impact of FYM addition on HR was assessed from August to October 2011, about 2 weeks after farmyard manure spreading (Table 2). For this purpose, two 9-m^2-areas were prepared in each of the three investigated FYM plots. One square in each plot was protected with a PVC sheet during manure application.

In order to measure HR, PVC rings (9.6 cm diameter) were inserted into the soil (3 cm) in each weeded area. In 2010 and 2012, four PVC rings were placed within a 1 m-side square centered on each weeded area. In 2011, six PVC rings were positioned in three staggered rows 50 cm apart, also centered on each weeded square.